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AIRCREW RESTRAINT SYSTEM - DESIGN CRITERIA EVALUATION

Richard W. Carr, et al

Ultrasystems, Incorporated

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EUSTIS DIRECTORATE POSITION STATEMENT

Significant advances in the state of the art of personnel restraint system performance characteristics have accrued over the past decade as a result of the emphasis placed on occupant safety by the directors of this nation's space program, and by legislators who promulgate regulations applicable to automobile safety requirements. Notwithstanding, the basic design of restraint systems presently used in Army aircraft has not been changed appreciably in many years.

In an effort to rectify this situation, the Army contracted for a program in 1970 which resulted in the formulation of a proposed draft military specification that defined a forward-facing aircrew restraint system for use in Army aircraft. The materials, design concepts, and features found to be desirable for maximizing occupant protection were included in the specification.

A subsequent program, which is the subject of this report, consisted of developing and testing a restraint system meeting the requirements of the specification to assure its adequacy and its adaptability to Army aircraft. This system represents the practical limits of current technology. Static and dynamic test conditions to which the restraint system was subjected were the most stringent ever successfully met under controlled conditions. It was demonstrated that the requirements of the proposed draft military specification can be achieved, and that the design and development of a modern, up-to-date restraint system for use in new-generation Army aircraft is feasible within current technology.

The technical monitor for this program was Mr. William J. Nolan, Safety and Survivability technical area, Military Operations Technology Division.

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The basic design of restraint systems used in Army aircraft has not changed for many years, and the restraint systems used today have not advanced to the practical limits of existing technology. In an effort to rectify this situation a proposed military specification defining a forward-facing aircrew restraint system for use in Army aircraft was formulated. The materials, design concepts, and features found practical for maximizing protection were included in the specification.

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The next step in the orderly development of an optimum restraint system that could be procured and used on aircraft was to demonstrate that the requirements of the specification were practical in terms of acceptable weight limits, that they were within reasonable cost, and that they were within existing production technology. Consequently, Contract DAAJ02-73-C-0050 was awarded to Ultrasystems, Inc., Dynamic Science Division, with Pacific Scientific Company (PSCo) as a major subcontractor. Dynamic Science performed the systems analysis and evaluation of the new restraint system design, and Pacific Scientific Company performed the detailed hardware design and fabrication.

After the systems analysis had been completed by Dynamic Science, hardware was designed and statically tested to the requirements of the proposed military specification. Design iterations were required on some hardware, and the design to be dynamically tested was developed. Dynamic testing of the aircrew restraint system revealed additional weaknesses, design modifications were again incorporated, and testing was reconducted until satisfactory results were obtained. The specification was modified and refined in necessary areas, with the net result that the specification as it now stands defines a restraint system providing optimum restraint for Army aircrewmen which can be built within the existing state of the art and for reasonable cost and weight.

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INTRODUCTION

The basic design of restraint systems used by the Army has not been changed for many years. Consequently, restraints used in Army aircraft today are not representative of current technology. To rectify this situation, the Army sponsored a program which was completed in early 1972 that consisted of a review of modern restraint system technology, an analysis of variables, and a concept development and test demonstration. This effort produced a draft military specification that defined an efficient forward-facing aircrew restraint system for use in Army aircraft.[1] A program to design a restraint system meeting the requirements of this specification was conducted under the present contract, DAAJ02-73-C-0050, by Ultrasystems, Inc., Dynamic Science Division, with Pacific Scientific Company as a major subcontractor. Also contributing to the technical design were two consultants in the field of occupant protection and crashworthiness: Dr. Richard G. Snyder of the University of Michigan and Dr. James W. Turnbow of Arizona State University. A summary of all the work completed during this program is contained in this report.

The objective of this program was to analyze, design, fabricate, and test an aircrew restraint system meeting the requirements of the proposed military specification, MIL-R-XXXX(AV), "Restraint System, Aircrew". The development approach established was to make maximum use of existing hardware. The intent of the overall effort was to modify and refine the specification as necessary to define the requirements for an optimum restraint system that could be fabricated within the state of the art.

Phase I of the program was used to analyze in detail the restraint system, as defined by the proposed specification, and to ensure that the design requirements were adequate but not overly restrictive. The requirements for each component were carefully studied to ensure that correct and complete criteria had been specified, and the test methods were reviewed to make sure that the important characteristics of the system would be tested. Special fixtures were designed to accomplish the static tests, and a test plan was prepared. Finally, a restraint system design complying with the specification was developed.

1. Kourouklis, G., et al, THE DESIGN, DEVELOPMENT, AND TESTING OF AN AIRCREW RESTRAINT SYSTEM FOR ARMY AIRCRAFT, USAAMRDL TR 72-26, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, June 1972, AD 746631.

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Phase II was devoted to fabricating and statically testing the restraint systems that had been designed in Phase I. The restraint systems were assembled by PSCo, while Dynamic Science fabricated the static test fixtures. After the tests were completed, results were used to establish and verify the performance requirements for the restraint system's components.

During the third and final phase of the program, two additional restraint systems, reflecting the design changes that evolved from Phase II, were fabricated by PSCo and then dynamically tested by Dynamic Science. Two dynamic tests were conducted to verify that the restraint system could adequately restrain a 95th percentile aircrewman during two impact environments that are representative of a 95th percentile survivable aircraft crash.[2] One test utilized a drop tower to produce a vertical impact, and the other used a horizontal test sled to produce a longitudinal impact. The results of the tests demonstrated that an aircrew restraint system meeting the requirements of the proposed specification could be designed and developed within current restraint system technology. The tests also provided empirical data for the overall evaluation of an improved aircrew restraint system and for the final revision of the proposed specification.

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2. CRASH SURVIVAL DESIGN GUIDE, USAAMRDL TR 71-22, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, October 1971, AD 733358.

RESTRAINT SYSTEM ANALYSIS

The initial task of the program was to perform an in-depth analysis of the aircrew restraint system as originally defined in the proposed draft military specification developed under Contract DAAJ02-70-C-0065 in 1971.

This restraint system, illustrated in Figure 1, was designed to mount on an aircrewman's forward-facing seat. It consisted of a single-point release buckle and tie-down assembly, left- and right-hand lap belt assemblies including side straps, left- and right-hand lower shoulder harness straps, a shoulder harness collar assembly, a dual-strap inertia reel, and two reflected inertia reel straps. The buckle assembly was a single-point release buckle connected permanently through a fitting to the tie-down strap assembly. The tie-down strap assembly consisted of a double strap of fixed length for a particular seat design that was connected beneath the cushion to the seat pan by a bolted fitting. The left- and right-hand lap belt assemblies included both a lap belt and a side strap that connected to the single-point release buckle. The lap belts were connected to the seat or aircraft structure through automatic lock-unlock retractors, while the side straps connected to the seat structure through adjuster/anchors. The lower shoulder harness straps attached to the bottom of the collar assembly through adjusters. The collar assembly consisted of a pad in the form of a collar, fitting around the occupant's neck with roller fittings attached near the top of the shoulders. The harness attaching the collar assembly to the seat consisted of two reflected straps with each strap extended forward from the inertia reel and routed around the roller fitting back to the opposite side of the seat back. These straps were attached to the seat through fittings on the reflected ends and through inertia reels at the other ends. The lap belt assemblies, tie-down strap assembly, and lower shoulder straps were all connected at the single-point release buckle.

A preliminary review of the restraint system configuration, shown in Figure 1, was accomplished by a Dynamic Science-Pacific Scientific Company Program Team. The advantages of the hardware design were reviewed, and areas that were shown to be overly restrictive or required additional detail to ensure adequacy of the restraint were recommended for modification. The testing established for demonstration of hardware compliance to the specification was also evaluated to ensure that it included sufficient and adequate tests.

Following this preliminary review, a detailed study of the proposed aircrew restraint system was made, with the findings of

ITEM IDENTITY

1. BUCKLE ASSEMBLY
   A. SINGLE-POINT RELEASE BUCKLE
   B. TIE-DOWN STRAP
   C. TIE-DOWN ANCHOR
2. LAP BELT ASSEMBLY
   A. LAP BELT (LEFT- AND RIGHT-HAND)
   B. SIDE STRAP (LEFT- AND RIGHT-HAND)
   C. RETRACTOR
   D. ADJUSTER/ANCHOR
3. LOWER HARNESS
4. COLLAR ASSEMBLY
   A. PAD
   B. ROLLER FITTING
   C. ADJUSTER
5. REFLECTED STRAP
   A. ANCHOR
6. INERTIA REEL

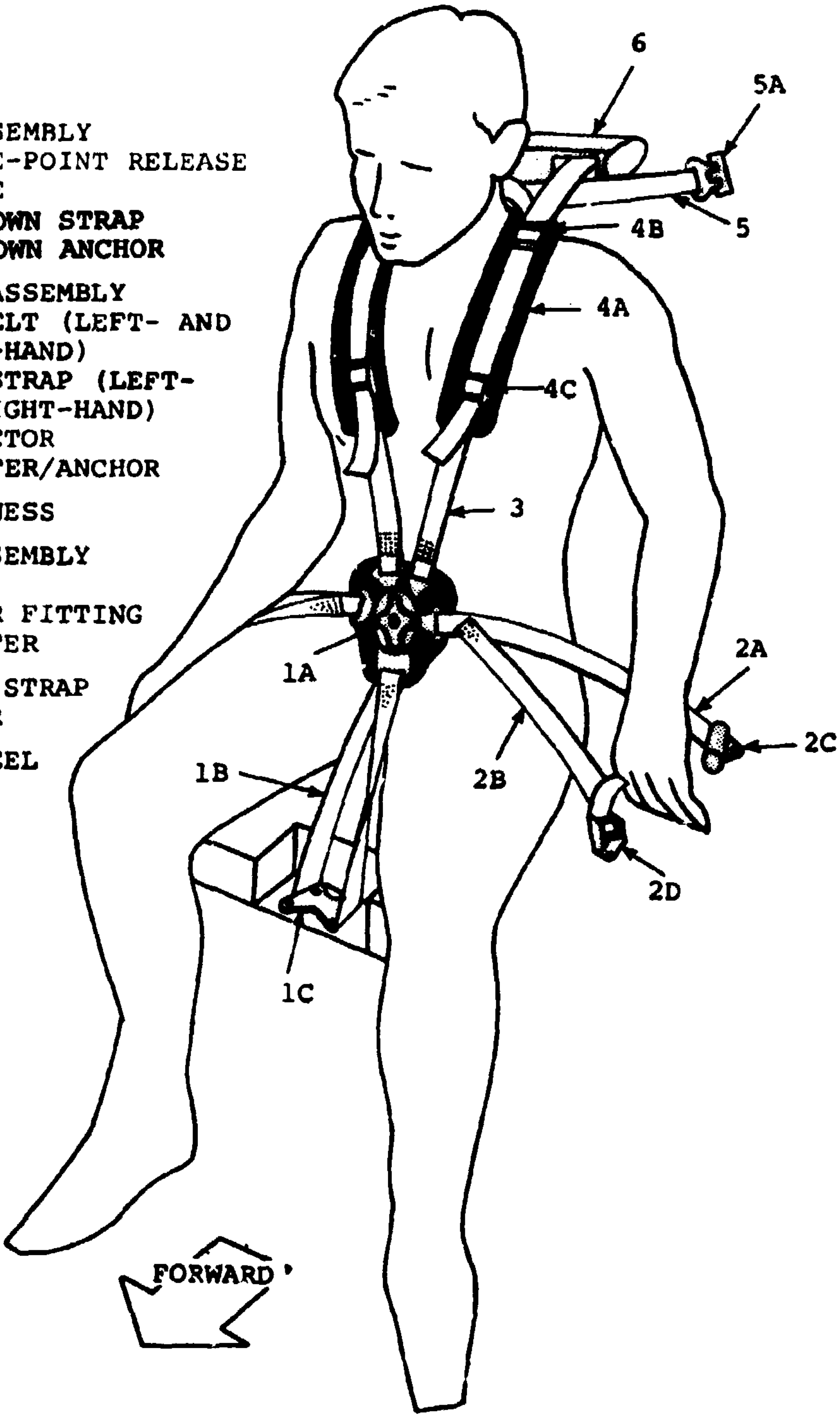


Figure 1. Beginning Aircrew Restraint System Configuration.

the preliminary review used as a guide. The restraint system components investigated during this study were:

- Inertia Reel
- Single-Point Release Buckle
- Lap Belt Retractor
- Lap Belt Assembly
- Roller Fitting
- Tie-down Strap
- Webbing

To assist in the investigations, a mock-up of the proposed restraint system was assembled by Pacific Scientific Company and was used to study the system's operational characteristics. The mock-up restraint system was configured to approximate the specification's drawings using existing components and webbing. The mock-up consisted of the following items:

1. Inertia Reel - Two MA-6 (0101 type) reels with 0.008-inch-thick power springs were used to permit 34 inches of 1.75-inch x 0.045-inch webbing to be retracted.

2. Reflected Straps - Fifty-four inches of 1.75-inch x 0.045-inch webbing with standard PSCo 0101240 fittings for anchors was used for each reel.

3. Collar Assembly - The pad was made from 2-inch-wide black nylon webbing 34 inches long. The roller fittings were simulated by chrome-plated end fittings stitched to the collar webbing, with two more of the same fittings facing the opposite direction and connected by a common pin through their attachment holes. The adjusters were standard PSCo flat adjusters mounted at the lower end of each collar assembly.

4. Lower Shoulder Harness Straps - Two-inch-wide nylon webbing was used for the shoulder harness straps.

5. Lap Belt Assembly - The lap belts (left-hand and right-hand) consisted of 2-inch-wide nylon webbing wrapped on PSCo Mark V retractors. The side straps (left-hand and right-hand) were Type I polyester webbing per MIL-W-25361 (1.75 inches wide) with PSCo flat adjusters for the adjuster/anchors. The adjusters were attached to one end of lengths of 2-inch-wide nylon webbing with standard anchors on the other end.

6. Buckle Assembly - The single-point release buckle was a standard PSCo rotary buckle, and the buckle pad was a round vinyl-covered pad.

7. Tie-Down Strap - Two types of tie-down straps were fabricated: (1) 1.25-inch-wide polyester webbing stitched to a buckle plug-in fitting and (2) 2-inch-wide nylon webbing with a standard PSCo slotted anchor at one end and a buckle plug-in fitting at the other end with a PSCo flat adjuster in between to permit variation in strap length.

The mock-up restraint system was mounted on a general-purpose seat in accordance with the seat mounting provisions of the proposed specification. This installation is illustrated in Figure 2. The operation of the restraint system under various conditions for different occupant sizes was examined and resulted in recommended changes to the specification for the inertia reel, buckle, side straps, and tie-down strap.

INERTIA REEL

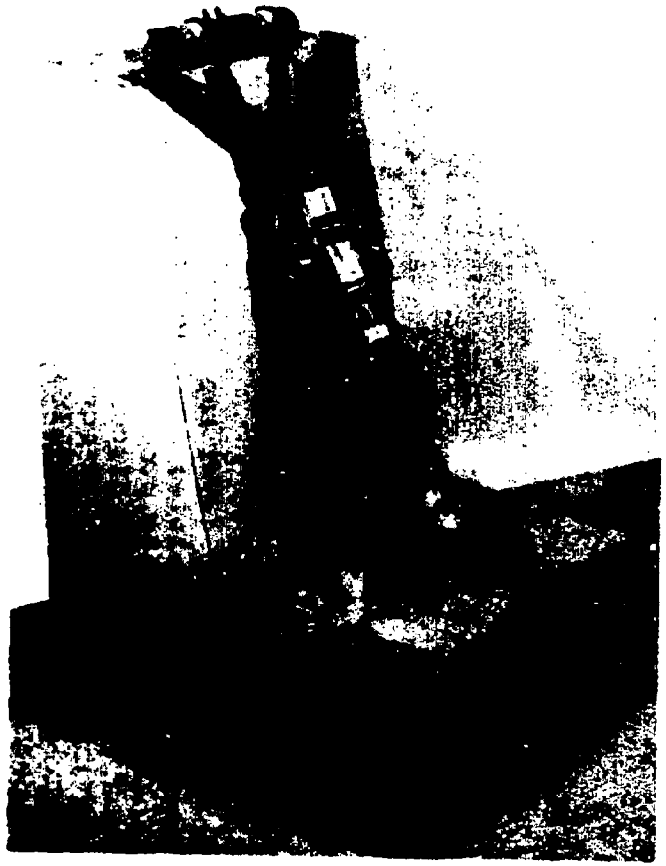
Several requirements for the inertia reel originally defined by the proposed specification were examined during the analysis. The inertia reel's

- configuration
- webbing length
- locking load
- retraction force

were studied, and the findings are presented in the following sections.

Inertia Reel Configuration

The inertia reel originally specified in the proposed specification was a dual-spool reel with a single inertia locking mechanism that conformed to MIL-R-8236C, Type MA-6. One of the primary reasons that a single dual-spool inertia reel was specified instead of two separate inertia reels was to ensure simultaneous locking of both shoulder straps, thereby eliminating the possibility of upper torso restraint by one shoulder strap in the event of a single reel failure. This would prevent any violent and potentially injurious rotation of the upper torso that might result from the different locking times of two separate inertia reels. Since it was believed that single shoulder strap restraint would be less desirable than none, successful operation of the restraint system with two inertia reels required locking of two separate units, thus decreasing the overall system's reliability.



Front Quarter View

Front View

Figure 2. Restraint System Mock-up.

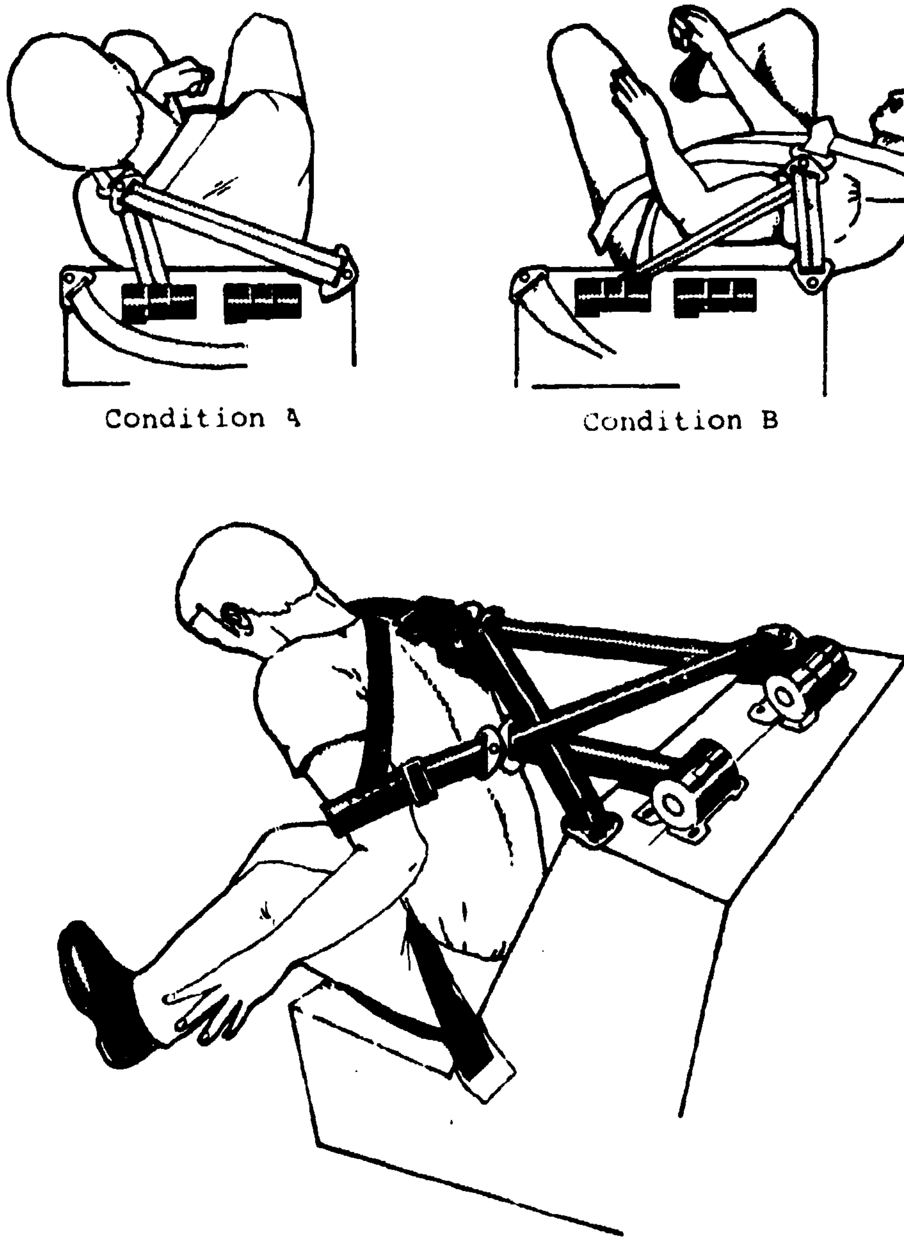
The principal disadvantage of a single dual-spool inertia reel stems from the requirements for occupant rotation and lateral movement in the performance of flight operations. This type of movement demands that different lengths of webbing be withdrawn from the individual spools, thus producing the necessity for independent spools. If the spools are not independent, then a rotation or a lateral movement of the occupant can cause a webbing backlash in the reel. For example, consider the occupant rotating to his right, thus requiring a much longer extension of the left shoulder harness than the right. Because both straps must unwrap equal amounts, excess webbing will be deployed from the right spool. The excess webbing will accumulate and eventually backlash the reel.

One possible solution to this problem is to use a differential gearing mechanism between the two spools, such as the one used in the F111 inertia reel. The differential permits the desired amount of webbing to be withdrawn from each individual spool, thus eliminating the backlash problem. Although use of the differential solves the backlash problem, it imposes heavy weight and cost penalties on the system.

The practicality of a single dual-spool inertia reel was discussed during the preliminary review, and it was decided to investigate the advantages and disadvantages of using two separate inertia reels. The possibility existed that a single strap restraint may be superior to no upper body restraint. If this observation proved to be correct, then the use of two separate inertia reels could be more reliable than the use of a single system. The probability of two reels not locking is significantly less than the probability of one reel not locking.

Also, previous tests conducted by PSCo demonstrated no locking problems with the use of two inertia reels. Rather, locking of the two reels occurred essentially simultaneously in all test cases and provided the desired crash protection while providing the improved flight operation characteristics. Further, dual reels have been used for many years on commercial jet airliners with no recorded evidence of either improper operation or failure of one reel to lock simultaneously with the other.

To investigate the merits of using two inertia reels, an analysis was performed which consisted of observing and evaluating the various loading conditions produced within the restraint system with one shoulder strap disconnected, simulating the failure of one inertia reel. The mock-up restraint system was used and the three loading cases illustrated in Figure 3 were studied: (1) decelerative loading of the occupant within the restraint system toward the side with the locked shoulder strap, (2) decelerative loading directly forward, and (3) decelerative



Condition A

Condition B

Condition C

Figure 3. Restraint System Loading With Single Inertia Reel Failure.

loading away from the locked shoulder strap. Loading into the locked shoulder harness (Condition A) produced excellent restraint because of the reflected strap and the location of the restraining member relative to the body loading. Loading away from the locked shoulder strap (Condition B) and pure longitudinal loading (Condition C) produced a lesser amount of restraint and considerably more body movement.

These results indicated that single strap restraint should be superior to no upper torso restraint. This can be explained by considering the configuration of the upper torso restraint system. Each reflected strap is attached to the shoulder harness collar of the restraint system through a roller fitting, providing a positive attachment between the seat structure and the collar. Since the shoulder harness collar passes around the occupant's neck and down through the lower shoulder harness strap to the buckle, a restraining member on the proper side of the neck does result if there is sufficient movement of the occupant. Although considerable movement of the upper torso is permitted, complete loss of restraint is not likely (1) because the length of webbing which can be removed from the unlocked reel is limited to the amount wrapped on the spool and (2) because of the transfer of load around the neck by the shoulder harness collar to the lap belt buckle.

A clear-cut answer as to which system is the most reliable is not presently available because of the lack of information concerning the probability of injury due to the extended movement permitted by the single strap restraint and the concomitant rotation. It is anticipated that the probability of injury from this type of restraint is less than that resulting from restraint by a lap belt alone but higher than the double strap restraint. Combining these considerations with the probability of successful locking of both inertia reels produces a problem which cannot be quantitatively answered at this time; however, it is felt that the probability of injury will not be increased by the use of two inertia reels over the dual-spool reel. Consequently, the specification was rewritten to permit the use of either two separate inertia reels or an acceptable single dual-spool inertia reel if one of reasonable weight and competitive cost is developed.

Inertia Reel Webbing Length

The Type MA-6 inertia reel specified by MIL-R-8236C is a single-strap reel with 18 inches of webbing travel. With the reflected strap configuration of the aircrew restraint system, the webbing travel of the inertia reel will have to be almost twice the distance of the occupant's forward motion. A full 36 inches of webbing travel is not required to permit the occupant 18 inches of forward motion because of the angular displacement of

the reflected strap. This is illustrated in Figure 4, where the webbing travel required for 18 inches of forward motion of the roller fitting is

$$(L_2 - L_1 + 18) \text{ inches}$$

The initial displacement of the roller fitting from the seat is 5.8 inches - the distance required by a 99th percentile Army aviator. This represents the extreme condition for webbing travel, which was calculated to be 31.4 inches for the condition illustrated in Figure 4. The length of webbing travel required by a 1st percentile occupant is 30.4 inches. Since some additional webbing travel will be required for adjustment, the requirement was established that the inertia reel be capable of holding 32 inches of webbing.

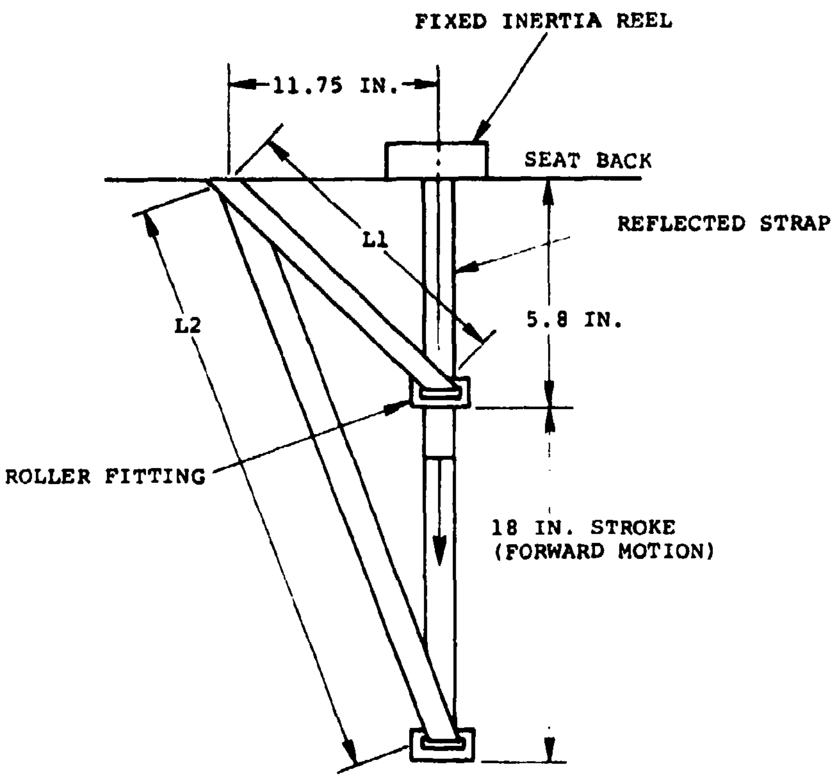


Figure 4. Inertia Reel Webbing Travel.

Inertia Reel Locking Load

The Type MA-6 inertia reel is required to lock when the webbing accelerations are 3G or above and not to lock at webbing accelerations of 2G or less. Using an inertia reel with a reflected strap will increase its sensitivity because of the pulley effect of the roller, which results in the inertia reel locking at lower shoulder harness accelerations. This increase in inertia reel locking sensitivity provides the occupant greater protection during a crash by locking the inertia reel and restraining the upper torso earlier in the crash sequence. The danger in having a more sensitive inertia reel is that it might lock during normal movement of the occupant. However, the inertia reel for the F111 restraint system has the same locking accelerations as the Type MA-6 inertia reel, and this configuration has proven to be operationally successful. Therefore, the locking acceleration for the aircrew restraint system's inertia reels conforms to those specified in MIL-R-8236C for a Type MA-6. This should not inhibit normal occupant movement and will make the restraint system more sensitive to inertia load, thus increasing occupant protection.

Inertia Reel Retraction Force

The webbing retraction force for a Type MA-6 inertia reel should be between 2 and 9 pounds. Because of the doubling effect of the reflected strap, and since two inertia reels will be used, the force applied to the occupant will be approximately four times the webbing tension in one inertia reel. Since this is a high load to move against under normal operating conditions, the webbing retraction force for each reel was reduced to between 2 and 4-1/2 pounds. The lower 2-pound limit is thought to be minimum force needed to retract the reflected strap, and the upper 4-1/2-pound limit is just half the highest retraction force for a single reel. This is consistent with retraction forces of an F111 inertia reel, which uses a single spring for both webbing spools that is adjusted to provide the Type MA-6 webbing retraction forces.

SINGLE-POINT RELEASE BUCKLE

The single-point release buckle originally defined by the proposed specification had several operational requirements that required further investigation:

- fitting release
- release force
- lap belt angle

These aspects of buckle operation were studied during Phase I. The results are discussed in the following paragraphs.

Buckle Fitting Release

The proposed specification initially required that the buckle release all of its fittings within 15 minutes of handle rotation. The intent of this requirement was to ensure the simultaneous release of all buckle fittings so that an injured crewman hanging in the harness would be released simultaneously. It might be disastrous for two or three restraint members to release while one remained in place, as it would severely jeopardize the occupant's chances of completing his exit from a stricken aircraft. However, there was some evidence that the 15-minute release angle requirement was too strict in terms of the cost involved in machining the buckle parts to the low tolerances that would be necessary for all fittings to be released simultaneously.

Since simultaneous release of all fittings is actually a function of the ability of the human to physically stop motion of the buckle release once sufficient force has been applied to release one fitting, an appropriate test was established and conducted using a PSCo rotary buckle to determine a more reasonable angular tolerance for fitting release. The test consisted of turning the buckle handle by hand with a 150-pound tensile load in the lap belt, representing the weight of a suspended occupant, and observing the release of the fittings. The results of this test indicated that it would be physically impossible to release less than all of the fittings when they are under this load. With the buckle fittings loaded, a release force must be applied through the handle that overcomes the frictional force between the fittings and the latch dogs. The instant that this frictional force is overcome, the handle will rotate to the stops, releasing all the fittings, because the release force being applied to the handle cannot be removed quickly enough to prevent the handle from fully rotating. Therefore, it was concluded that all fittings need not be released within 15 minutes of each other, thus permitting larger tolerances in machining and permitting a lower priced buckle.

A more reasonable fitting release requirement was initially thought to be for all fittings to be released within 2 degrees of handle rotation. This requirement was examined again during the static tests, and it was established that the handle rotation angle between release of the first and last fittings could be as high as 15 degrees (see Buckle Release Test).

Buckle Release Force

The force required to release a loaded buckle mechanism was also examined by testing a PSCo rotary buckle. A lap belt assembly with a buckle was installed in a tensile test machine, and the torque required to open the buckle was measured with various loads in the lap belt. The measurements were made with a torque wrench and spring scale. The spring scale was used to measure the force required to open the buckle with one point load application, simulating the case of an injured occupant attempting to open the buckle with, for example, an injured wrist. The spring scale was attached to the outer edge of a handle vane, and the force required to turn the handle and release the fittings was measured. The torque wrench was used to measure the torque required for normal two-fingered operation (i.e., thumb and forefinger placed on opposite vanes, forcing the buckle handle to rotate) through the applied couple. The measured results of this test are given in Table 1, along with a subjective indication of the difficulty in opening the buckle. Since the single-point application of the load represents an extreme condition, the maximum release torque was chosen to be 22-1/2 inch-pounds, which is the torque generated by a release force of 18 pounds applied 1-1/4 inches from the center of the buckle.

TABLE 1. PRELIMINARY BUCKLE RELEASE TEST RESULTS

Webbing Load	Torque (in.-lb)	Force* (lb)	Opening Resistance
250	50		High
200	40		High
150	30		Medium
100	20	18	Medium
50		10	Low

*Single-point application - 1-1/4" from buckle center.

Buckle Lap Belt Angle

The restraint system mock-up was used to study the position of the single-point release buckle on the occupant, and it indicated that the lap belt fittings should attach to the buckle at an angle. The tie-down strap of fixed length will position

the buckle low in the lap of the occupant, causing the lap belt to pass over the occupant's upper thighs and enter the buckle at an angle that is above the horizontal centerline of the buckle. This results in the lap belt fittings' being rotated closer to the shoulder harness fittings. Using the restraint system mock-up, this angle was roughly measured on several occupants and was found to vary between 15 and 27 degrees. This appeared to indicate that a nominal 20-degree entry angle for the lap belt would place the lap belt fittings in a good position for all occupant sizes. A schematic illustration for this buckle assembly configuration is shown in Figure 5.

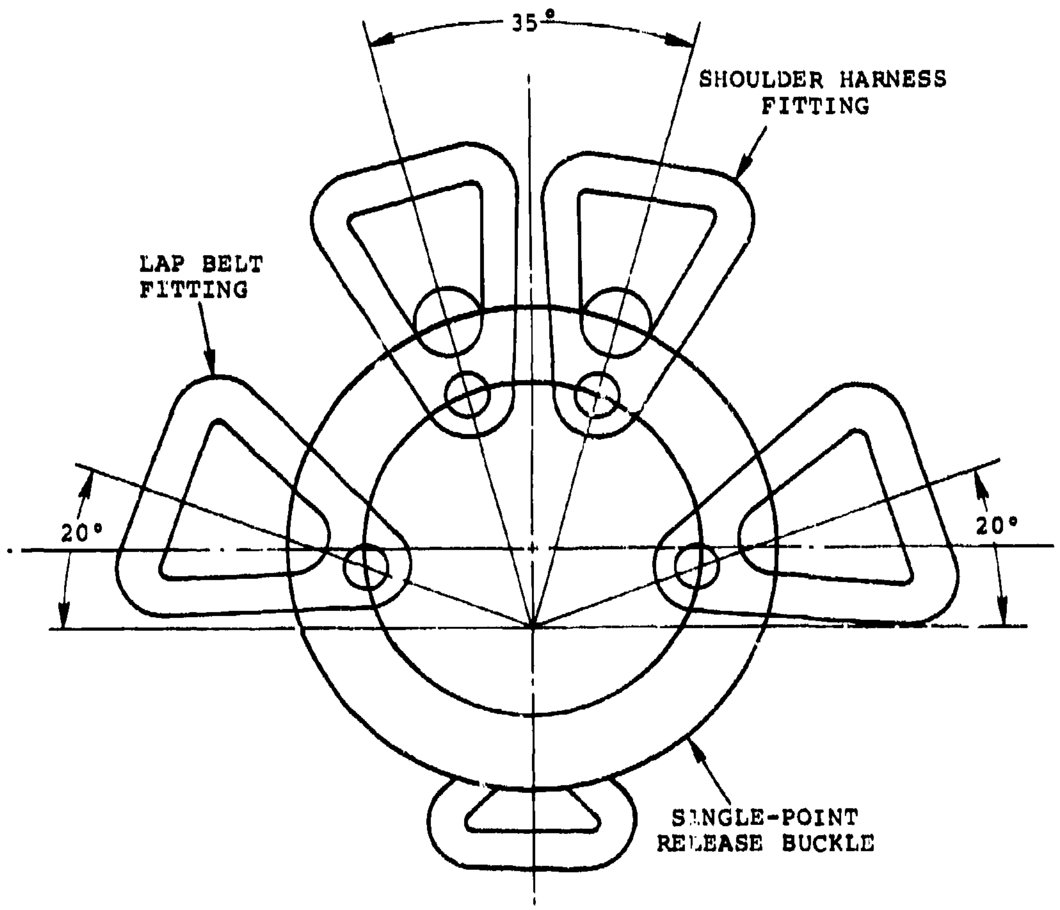


Figure 5. Buckle Fitting Attachment Angles.

The normal operation of the buckle as... is greatly enhanced ... the lap belt fitting engages the buckle at an angle above ... horizontal. If the fitting attaches with no angle or at an ... below the horizontal, the buckle must be rotated to ... each lap belt fitting, which complicates the securing of ... restraint system. These entrance angles also widen the ... surface of the buckle and fittings in an area where lateral space is very limited. This could result in discomfort to the occupant over a long period of time.

... attachment or entry angle for the lap belt fittings is also ... from the standpoint of loading the webbing and fit... If this angle is above the horizontal centerline of the buckle, the fittings are coincident with the load path of ... webbing and there would be no bending of the fitting or ... loading of the webbing in the plane of the buckle which might cause premature failure of the belt. An attachment angle at or below the horizontal centerline places the fitting at an angle to the load path of the webbing and might produce bending stresses in the fitting and edge loading in the webbing

Therefore, based on enhancement of normal operation, increased comfort, and the improvement of loading conditions that would apparently result from the angled lap belt fitting termination ... the buckle, it was initially recommended that the attachment angle for the lap belt fitting be 20 degrees above a line parallel to the horizontal centerline of the buckle. However, during fabrication, the lap belt entry angle was reexamined, ... it was decided to also permit a lap belt entry angle of ... 0 to 20 degrees to permit flexibility in design constraints, providing the system could be demonstrated to adequately carry the required load imposed by the tests specified. (See Restraint System Fabrication.)

... BELT RETRACTOR

... area of the proposed specification that was felt to be ... restrictive and possibly detrimental to the operation ... the restraint system was the lap belt retractor force. The maximum force of 30 pounds was suspected to be too high for aircrewmen comfort during extended usage. To investigate this possibility, a simple experiment was conducted. A test subject was seated in an office chair, wearing a special lap belt to which weights could be attached. These weights were varied between 15 and 30 pounds, and the resulting lap belt pressure was subjectively measured.

With the 30-pound weights attached to each side of the lap belt, the pressure was judged to be quite severe. The lap ... force greatly restricted movement of the occupant and

caused numbness of the leg and pain at the hip after a period of 1 hour. The lap belt weights were then reduced in 5-pound increments until a tolerable lap belt force was found. This occurred when the weight attached to each side of the lap belt was 15 pounds. The 15-pound lap belt force was found to be tolerable for a period of 3 hours and produced no numbness of the leg or pain at the hip joint. Therefore, the maximum retractor force was changed to 15 pounds, and the minimum retractor force was set at 7-1/2 pounds.

The proposed specification also required that the retractor fully retract the lap belt webbing before the locking mechanism released. The purpose of this requirement was to be sure that the retractor would lock any length of lap belt webbing once pulling motion of the lap belt had stopped or had been reversed. However, there is a minimum length of lap belt webbing required for even the smallest occupant, and requiring the lap belt retractor to lock at lengths less than the minimum length is not really necessary and detracts from the ease of operation. It is only necessary for the lap belt retractor to lock for webbing lengths greater than the minimum, or "unlock", length. The unlock length was defined to be the shortest length of lap belt required to span the unoccupied seat cushion with the buckle located on the cushion centerline.

LAP BELT ASSEMBLY

A study of the lap belt assembly using the restraint system mock-up indicated that the usefulness of the side strap included in the specified restraint system was questionable. The side strap severely restricted the freedom of motion of the occupant's legs. Since the distance between the seat pan and the floor in most helicopters is considerably less than the distance between the occupant's knee and heel, retraction of the legs toward the seat requires that the thighs lift up away from the forward part of the seat pan. If the side straps are adjusted with the legs extended and feet on the rudder pedals, leg retraction is impossible because of the vertical restriction provided by the tight side strap. To permit freedom of movement, the side straps would have to be adjusted with the heels withdrawn to the rearmost position. This would result in considerable slack in the side straps when the feet are placed back on the rudder pedals, thus reducing the restraint capability when needed. The side straps also required adjuster/anchors and were sewn to the lap belt webbing at the buckle fitting, thus complicating the system. The adjuster/anchors required that the occupant adjust both side straps in addition to the lower shoulder straps when adjusting the restraint harness. This meant that, even with inclusion of the retractors on the lap belt, the number of adjustments required

was still equal to that of existing systems and the desired reduction in system complexity had not been achieved. The side straps also reduced the amount of lap belt webbing which can be withdrawn from the seat pan by the retractors, subtracting from the effectiveness of these components.

As mentioned in the previous paragraph, improvement of lateral restraint was seriously impaired by the slack resulting from proper adjustment of the side straps. The straps were located as far rearward as possible to minimize interference with leg movement, which placed them very near the hip joint. Therefore, a small amount of slack seriously degraded the ability of the strap to limit lateral leg pivot because the strap contact point with the leg is close to the leg pivot point (hip joint). Lateral movement of the occupant would undoubtedly be reduced somewhat by the side straps; however, the improved resistance to "submarining" due to straps on the sides would be minimal because of the slack in the webbing.

Another aspect of this lateral restraint problem is that most Army seats today have some sort of side panels on the seat buckets, which provides some lateral restraint to the leg. Since these panels will provide restraint prior to significant loading of the side strap, it was decided that this function should be better assigned to the seat design. Therefore, the side strap and the adjuster/anchor were deleted from the aircrew restraint system. Elimination of the side strap was not inconsistent with earlier studies recommending the addition of thigh straps[3] since the suggested configuration for the thigh straps was slightly different and their primary purpose was to prevent "submarining". In the aircrew restraint system this function is provided by the tie-down strap and proper mounting of the lap belt assembly.

ROLLER FITTING

A close examination of the roller fitting revealed that the angle between the reflected strap and the roller fitting would change as the occupant's upper torso moved forward and might cause edge loading or folding of the webbing at the roller fitting. It was therefore decided to examine the angle required for complete upper torso motion using the restraint system mock-up with the roller fitting mounted on a swivel joint. With the occupant sitting in an upright position, the initial position of the roller fitting was rotated away from the occupant (outboard) approximately 5 degrees as measured from a line

3. Pesman, G. J., and Eiband, A. M., CRASH INJURY, NACA-TN-3775, National Advisory Committee for Aeronautics, Washington, D.C., November 1956.

perpendicular to the seat back. As the occupant's upper torso moved forward, the roller fitting angle became smaller, passed through zero, and ended up being oriented approximately 15 degrees in the opposite direction (inboard) after the shoulders had traveled 18 inches. This meant that the angular motion of the roller fitting was approximately 20 degrees. Since this angle was relatively small, the roller fitting mounting then currently specified (i.e., looped in webbing) was judged to be flexible enough to allow the fitting to rotate sufficiently so that folding or edge loading of a reflected strap would not cause a problem. To provide freedom for rotation of the fitting, it was decided that the mounting loop in the webbing should be stitched together at the fitting and then attached to the collar 1 inch below the fitting.

Another design requirement for the roller fitting was that there also should be enough clearance between the roller and frame to permit the reflected strap anchor to pass through. This would allow the installation of new inertia reels without requiring that the webbing be removed from the inertia reel spool.

TIE-DOWN STRAP

One result of the preliminary analysis was that a modification of the tie-down assembly was investigated. This modification included making the seat pan attachment fitting narrower, thus bringing the separate straps closer together and eliminating the possible interference with the inside of the occupant's thighs. It was further recommended that an alternate design in which the tie-down webbing is brought directly from the buckle fitting to a suitcase handle type attachment located at an appropriate point on the seat pan be considered over the separated twisted strap concept originally specified.

The original tie-down strap design was configured to provide separation of the two straps that make up the assembly. The objective of this design was to permit an opening between the two tie-down straps to eliminate anxiety of crewmen concerned with groin injury that might result from an impact against a centrally located strap. The twist in the separate strap approach was to provide a flat contact surface for the inside of the thigh, thereby producing improved lateral restraint.

During the preliminary analysis, it was pointed out that the two straps could produce a load acting to hold the occupant's legs too far apart and cause fatigue or thigh irritation. The solution to the potential problem was to reduce the spread between the two straps, however, since reducing the spread between the two straps eliminated the separation, the psychological advantage of the double strap was also eliminated. This

produced two competitive concepts which were reviewed prior to final selection. The first was simply to reduce the width of the tie-down fitting on the seat pan, thus moving the straps closer together and maintaining the twist which produced flat webbing contact with the inside of the thighs. The second was to use a single piece of webbing, probably lapped over and stitched to form a double fitting. This latter approach was the simplest of the two concepts and was the one recommended for use in the aircrew restraint system.

Tests conducted with the mock-up restraint system using occupants ranging from the 51st to the 99th percentile indicated that a single-length tie-down strap would be adequate. It was determined that a single length of 8 inches, measured from the center point of the buckle to the seat pan surface, was equally comfortable for all occupant sizes. The reason is that as the thighs of the larger occupant become thicker and raise the buckle, his torso also becomes thicker, causing the buckle to move forward in an arc about its tie-down point. As the occupant becomes smaller, his thighs become thinner, as does his body, permitting the tie-down strap and buckle to rotate toward the seat back and seat pan, again around a radius of the strap length. It was concluded, therefore, that adjustment of the tie-down strap was not required, which was in agreement with the proposed specification.

WEBBING

It was extremely desirable for the webbing in the restraint system to have relatively low elongation in order to minimize the effects of dynamic overshoot. The ideal elongation for the webbing at its design load should be 5 percent or less. Commercial webbing with this low elongation at the design loads of the aircrew restraint system was not readily available; however, discussions with webbing suppliers indicated that it would be possible to develop a webbing with an elongation of less than or equal to 5 percent. Therefore, all known webbing manufacturers were contacted by Pacific Scientific Company and requested to quote on supplying a low-elongation polyester webbing that would satisfy the requirements of the proposed specification. The requirements given to the webbing companies were that three separate webbings should be fabricated from untreated polyester material per MIL-W-25361, Type III, with the necessary exceptions to comply with the following requirements:

(1) 1.25 ±0.06 inch wide x 0.055 ±0.010 inch thick, 4,000 pounds breaking strength, and 2,500 pounds design strength.

(2) 1.75 ±0.06 inch wide x 0.055 ±0.010 inch thick, 6,000 pounds breaking strength, and 4,000 pounds design strength.

(3) 2.25 ±0.06 inch wide x 0.055 ±0.010 inch thick, 6,000 pounds breaking strength, and 4,000 pounds design strength.

(4) 5 percent elongation at design strength for all sizes.

(5) Color - Olive drab No. 7.

Webbing Development

The investigation into the development of extralow-elongation webbing disclosed that the facilities for such an undertaking were minimal. A survey of twelve webbing manufacturers, including all of the leaders in this field, yielded just one supplier willing to embark upon a development program during the time span requested. Some companies were very interested in the requirements, but were unable to assist because of unusually heavy work loads in their plants, and offered their assistance at a later date when conditions would permit. Others were nonresponsive because they were not currently weaving polyester or had minimum-order requirements of thousands of yards per size.

The results of the supplier survey are summarized below:

1. American Cord and Webbing Company, Inc., New York, New York - a company representative stated that they do not weave much polyester webbing and when they do, a 25,000-yard minimum order is required.

2. Arbeka Webbing Company, Pawtucket, Rhode Island - The company's vice-president of sales said they were not currently weaving polyester webbing. He suggested that Murdock Webbing Company be contacted.

3. Balley Ribbon Mills, Balley, Pennsylvania - The production superintendent recommended that Phoenix Trimming Company be contacted for low-elongation, polyester webbing. He did, however, suggest that they could provide the desired sizes and elongations if the webbing could be made of a new material identified as "Fiber B" that they have produced. This idea was set aside for future consideration because of the developmental status of the material.

4. Buffalo Weaving and Belting, Buffalo, New York - This company is a custom weaving shop that specializes in webbing for arresting gear. Their experience, therefore, was in manufacturing thick webbings with high elongation.

5. Burlington Ribbon Mills, South Hill, Vermont - A company representative stated that they were currently in the midst of the 1974 automobile year's webbing manufacture and were operating at capacity. He did offer the comment that they had made some webbing for an automobile manufacturing company with 3.3-percent elongation measured at 2,500 pounds.

6. Fabrication and Development, Inc., Souderton, Pennsylvania - This is a company that specializes in the development of textiles. The company's president sent a proposal that described a three-part plan to satisfy our request. The three approaches were to use: (1) polyester with a hot-drawn technique, (2) polyester wrapped on fiberglass, or (3) "Fiber B" yarn. Each of these methods would have required four months' time and were too expensive for this program.

7. International Webbing, Inc., Whitehall, Pennsylvania - A sales representative said that they did not fabricate polyester webbing, and he stated that they require a 50,000-yard order to weave a new size. He also recommended Murdock Webbing Company and Buffalo Weaving and Belting as suppliers of polyester webbing.

8. Murdock Webbing, Inc., Central Falls, Rhode Island - A company representative stated that their production shop was loaded to capacity into the third quarter of 1973 and, on some equipment, well into 1974. Heavy demand was caused by requirements of the 1974 automobile production. They did state, however, that small development quantities could be run in their research and development department and that they would give extra consideration to this request for the three sizes of special low-elongation webbing. Subsequently, they notified PSCo that they would proceed immediately to make 100 yards of each size.

9. Narricot Industries, Inc., Philadelphia, Pennsylvania - The director of R&D disclosed that they completely understand the problem of producing low-elongation webbing in special sizes, and he indicated that they are research oriented and would like to have the chance to work on such a project. However, their production shop was filled with large 50,000-yard orders

for automotive webbing at that time, although this situation could easily change in two or three months. This company also reported information concerning an automotive webbing with elongation in the 6- to 8-percent range measured at a load of 2,500 pounds.

10. Phoenix Trimming Company, Chicago, Illinois - A discussion of the webbing requirement with the engineering vice president indicated that the specified webbing is possibly beyond the present state of the art. Their best production effort at the time was 12-percent elongation. He did suggest the use of "Fiber B" because of its higher tensile strength. Again, low-elongation automotive webbing was discussed. Phoenix Trimming had made webbing with 3-percent elongation at 2,500 pounds (7,000 pounds breaking strength) as a special project for an automobile manufacturer. Mention was made of a new piece of equipment, currently being installed, that was scheduled to be operational about the middle of September 1973. This equipment was expected to improve webbing elongation characteristics considerably.

11. Prodesco, Inc., Perkasie, New Jersey - This company is a small-order webbing supplier. The marketing vice-president promised a quotation for polyester webbing; however, he recommended the use of "PRD 49" yarn, which is a modification of "Fiber B". This source might be considered in the future if a non-polyester yarn is given further consideration.

12. Southern Weaving Company, Greenville, South Carolina - The sales manager disclosed that their looms would be operating at capacity for up to 8 months, to fill mostly automotive orders. They investigated breaking into their production looms schedules in order to accommodate this request, but with negative results.

Summary of Webbing Suppliers

At the time, there was only one source of special sizes of extralow-elongation polyester webbing available: Murdock Webbing Company. The webbing for the aircrew restraint systems was obtained from them. However, there were three other companies that expressed a sincere desire to help if they could arrange the schedule time and/or special equipment necessary for the task. These companies were: (1) Narricot Industries, (2) Phoenix Trimming, and (3) Southern Weaving.

Low-Elongation Webbing Problems

The real deterrents to low-elongation polyester webbing production, after the scheduling situations are cleared, are the two problems of yarn stretching and dyeing. Low elongation is produced by stretching the webbing as it is being woven. The webbing must be stretched to its limit and then this condition retained by the application of heat (heat setting). As this process reaches the extreme, the yarn becomes brittle, breaking easily and having low abrasion characteristics. Further, most of the equipment being used at present does not have sufficient strength to stretch the heavier sizes of webbing that could produce the desired extralow-elongations. In this process, there are trade-offs in the amount of stretch and heat set, yarn size, weave configuration, and breaking strength which determine the elongation characteristics of a particular webbing. The other deterrent to low elongation is color dyeing. Moisture increases elongation as shown by the fact that two suppliers mentioned that their chances of attaining the required 5-percent elongation would be considerably improved if they could leave the webbing in its natural (white) color. One suggested that environmental parameters of 70° ±2°F and 65 ±2 percent relative humidity be established when testing for elongation because polyester is very sensitive to these variables.

Preliminary Webbing Tests

Three 50-yard rolls of low-elongation webbing were received with properties somewhat different than desired. The results of the supplier's tests on the three sizes of webbing are as follows:

Width (in.)	1.25	1.75	2.25
Thickness (in.)	0.043	0.047	0.043
Breaking Strength (lb)	4,366	6,740	7,620
Elongation (pct)	8.2	10.0	7.5
Elongation Load (lb)	2,500	4,000	4,000

These results compared quite closely with tests run on samples at Pacific Scientific Company's test laboratory. The load-elongation curves from both sets of data are shown in Figures 6 and 7.

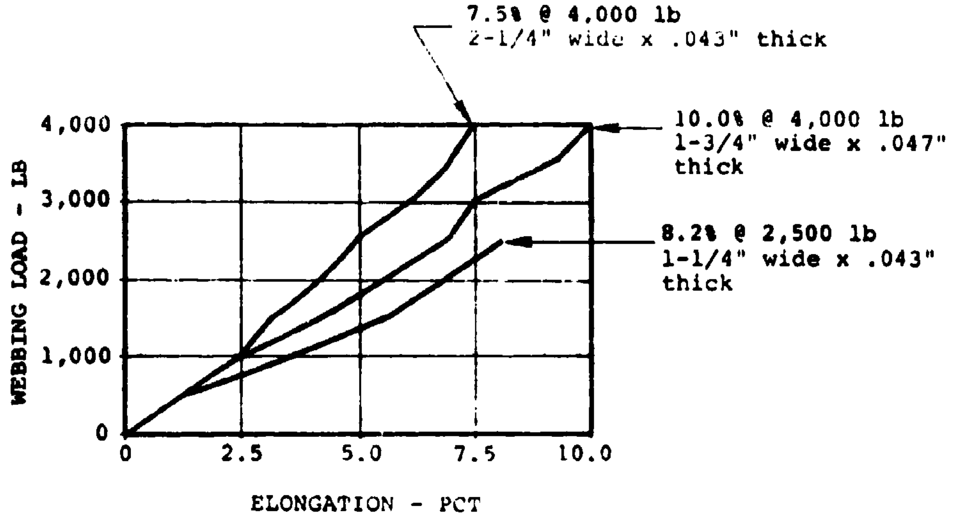


Figure 6. Webbing Load-Elongation Curves (Supplier Data).

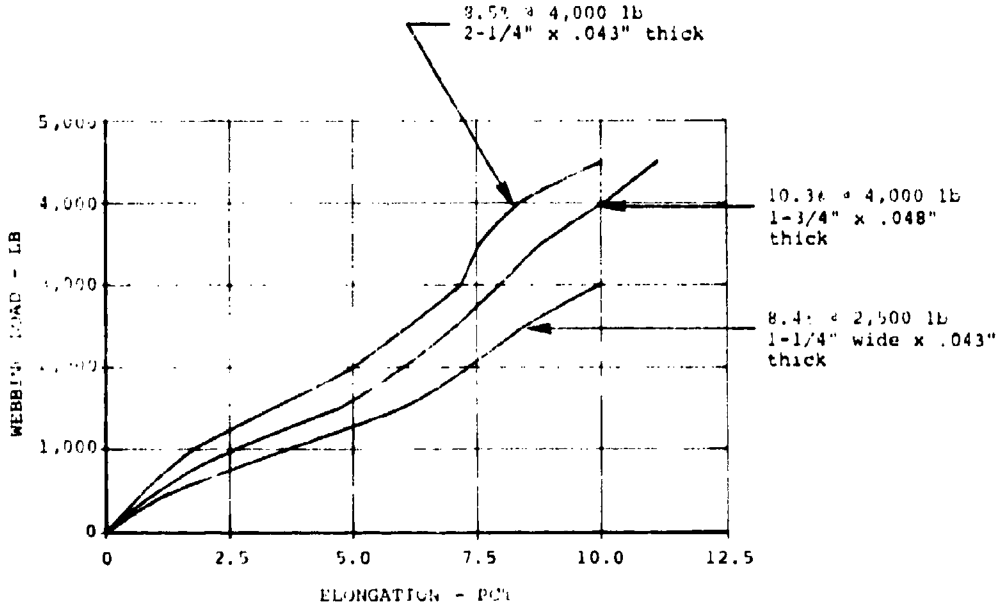


Figure 7. Webbing Load-Elongation Curves (PSCo Data).

Alternate Webbing Sources

The supplier, after recieving comments from PSCo, Dynamic Science, and USAAMRDL, offered to make a second attempt at conforming to the 5-percent elongation and 0.055-inch thickness requirements. This was based on the availability of production time on new heat setting equipment. They were also installing a "Thermosol Dye Range" which, being automatic, should eliminate hand control of the thermal factors and make a more consistent product.

Consideration was also given to the use of existing and available low-elongation webbing. Contact was made with potential webbing suppliers for a check on presently available webbing that would come close to meeting the requirements. Another supplier reported that their work load had increased to the point that they were doing production work in their research and development shop, although this condition was expected to last only until mid-September 1973. This supplier had available some 1.938-inch-wide, 0.045-inch-thick webbing (pattern 72-349) with a breaking strength of 6,450 pounds. Because this is automotive webbing, the elongation is measured at 2,500 pounds and is 6.75 percent. Examination of the elongation data for this webbing (see Figure 8) showed that the elongation was 10.7 percent at 4,000 pounds.

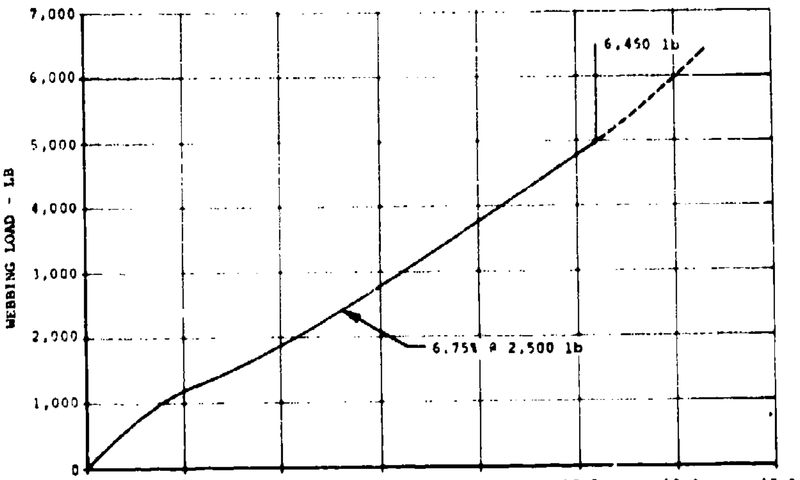


Figure 8. Load-Elongation Curve for Alternate Supplier's 72-349 Webbing.

The only other potentially applicable webbing that this supplier had in stock was a narrow, thick size (pattern No. 1499). This material was 1.031 inches wide and 0.082 inch thick with 6-1/2-percent elongation at 2,500 pounds load. The load-elongation characteristic of this webbing is illustrated in Figure 9. This webbing was a candidate for the tie-down strap application with a design load requirement of 2,500 pounds.

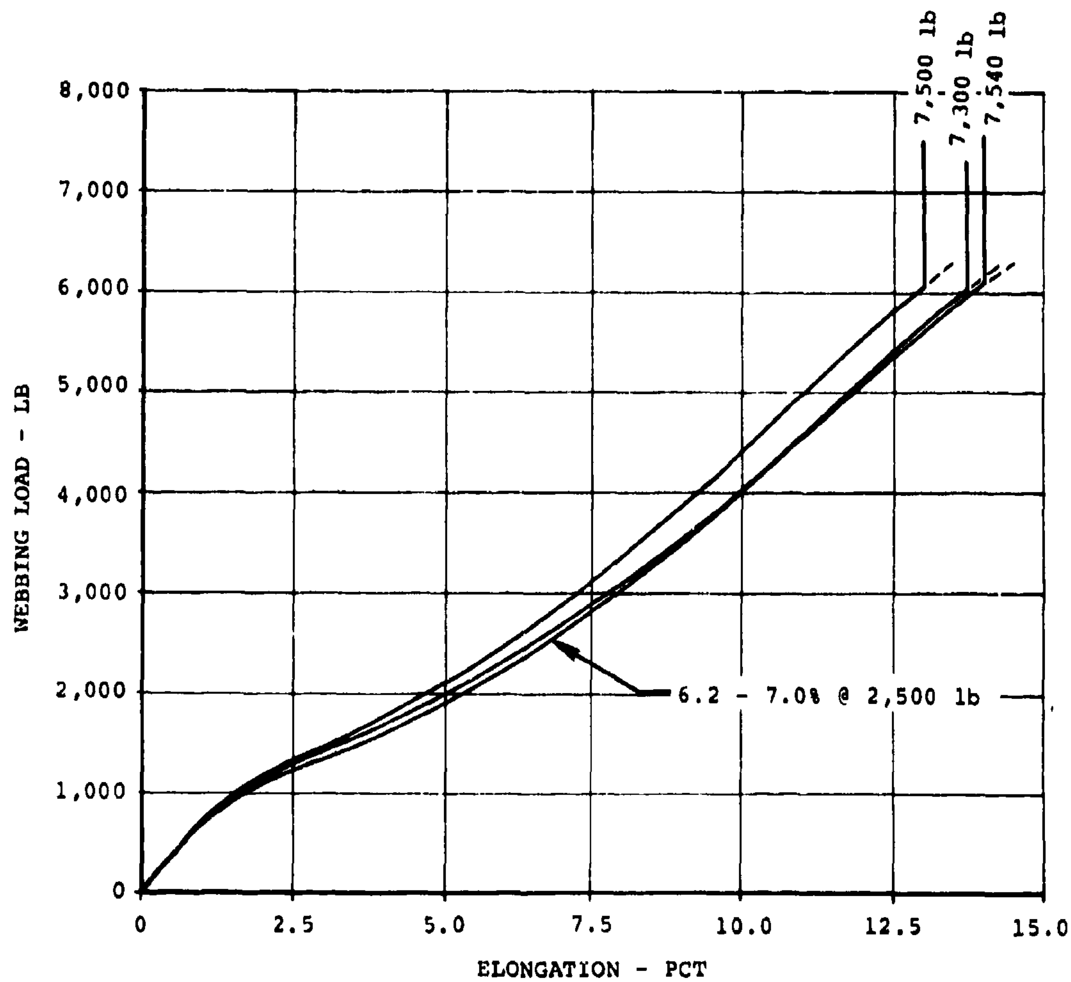


Figure 9. Load-Elongation Curve for Alternate Supplier's 1499 Webbing.

A check with another supplier disclosed that their plant was still running at full capacity. They were making an automotive webbing "1200XP" that was four-panel polyester, 2 inches wide, with 6,000 pounds breaking strength. This was rated at 9-percent elongation per Motor Vehicle Standard JE22. No test reports were available, but a sample roll could be obtained.

Polyester Webbing Environmental Properties

An area that required further definition was the resistance of polyester webbing to environmental extremes. This information was required to define the service life of the webbing and to ensure that the webbing would meet the environmental conditions of the specification. These conditions required that the webbing withstand exposure to

- temperature
- sunshine
- humidity
- fungus
- salt fog
- dust

and not deteriorate or change its physical characteristics beyond that required to meet the design requirements. Exposure to dust and fungus was judged to be nonapplicable to a polyester webbing since it is reasonable to assume that dust particles would have no noticeable effect on the webbing's mechanical properties. Tests by fiber manufacturers have demonstrated that polyester will not support or be damaged by fungus. There is a possibility that a coating or lubricant could be applied to the webbing that might be susceptible to a fungus attack. However, this possibility could be prevented by specifying that the webbing have no coatings or lubricants applied to it.

To determine the effects of the remaining environmental parameters, data on polyester fibers or webbing in the form of published documents were requested and subsequently received from major fiber suppliers. The following results were gleaned from the sources:

Resistance to Humidity and Salt Fog

Polyester fiber has excellent resistance to both humidity and salt fog. Dacron* polyester fiber will retain at least 90 percent of its original breaking strength after

*Trademark.

being exposed to a saturated solution of sodium chloride at 21°C for 1,000 hours and after being soaked in water at 99°C for 100 hours.[4] The average strength and elongation and the percentage change in these characteristics for both nylon and Dacron webbings exposed to a high humidity and salt spray environment are shown in Table 2.[5] These are presented for comparison purposes and to illustrate the increased performance of Dacron webbing. The exposure for both tests was 24 hours. The webbings were woven from Type 52 Dacron and Type 702 nylon in a double plain weave, per MIL-W-4088, Type XXII, with a nominal width of 1.75 inches. The conditions for the humidity test were a temperature of 70°F and a relative humidity of 96 ±2 percent. The salt spray test was conducted in accordance with MIL-D-5272C(ASG) and MIL-STD-151, Method 811.1.

TABLE 2. WEBBING HUMIDITY AND SALT SPRAY TEST DATA[5]

	Failure Load (lb)	Failure Load Change (%)	Elongation (%)	Elongation Change (%)
Dacron (control)	5,210		15.6	
Humidity Test	5,130	-1.5	16.7	+7.1
Salt Spray Test	5,050	-3.1		
Nylon (control)	4,670		23.2	
Humidity Test	4,310	-7.7	25.9	+11.6
Salt Spray Test	4,650	-0.4		

4. THE CHEMICAL RESISTANCE OF "DACRON" DuPont Technical Information Bulletin D-235, February 1970.

5. Freeston, W. D., Jr., and Johnstone, D. S., HIGH-TEMPERATURE ABRASION-RESISTANT PARACHUTE RISER MATERIALS, Technical Report AFML-TR-67-323, Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433.

Resistance to Temperature Extremes

The changes in nylon and Dacron webbing strength and elongation after exposure to temperature extremes generally indicated that elongation is directly proportional to temperature while breaking strength is inversely proportional. Dacron has better resistance to temperature extremes than nylon. The effect of heat exposure on the breaking strength of Dacron and nylon fibers is shown in Figure 10.[6] The changes in strength and elongation of these fibers after exposure to several high-temperature environments are given in Table 3.[7] The change in failure load of webbings made from nylon and Dacron after being exposed to temperatures between +250°F and -65°F for 24 hours is shown in Table 4.[5] The webbings used for these tests were the same as the webbings used for the tests given in Table 2.

Resistance to Sunlight[8]

The exposure of webbing to sunlight over long periods of time can cause deterioration of the fibers and a reduction in the strength of the webbing. Tests and experience indicate that ultraviolet rays with wavelengths of 290 to 400 millimicrons are the primary cause for radiation damage to fiber products. Radiation with wavelengths above 400 millimicrons (i.e., the visible and infrared rays) can cause an increase in fiber temperature that may either accelerate ultraviolet degradation or cause heat degradation; however, these longer light waves are usually a minor cause of fiber deterioration. Radiation with wavelengths of less than 290 millimicrons (e.g., gamma and Xrays) is seldom encountered by fiber products; hence, their effects can be disregarded.

The spectral distribution of radiation within the range of 290 to 400 millimicrons is also an important factor in the deterioration of fibers by light. Some fibers are damaged principally by radiation at the lower end of the ultraviolet range, while others are affected to a greater degree by radiation at the higher end of the ultraviolet

6. HEAT DURABILITY AND HEAT SHRINKAGE OF YARNS, DuPont Technical Information Bulletin X-111, September 1959.

7. COMPARATIVE HEAT RESISTANCE OF FIBERS, DuPont Technical Information Bulletin X-56, September 1956.

8. LIGHT AND WEATHER RESISTANCE OF FIBERS, DuPont Technical Information Bulletin X-203, April 1966.

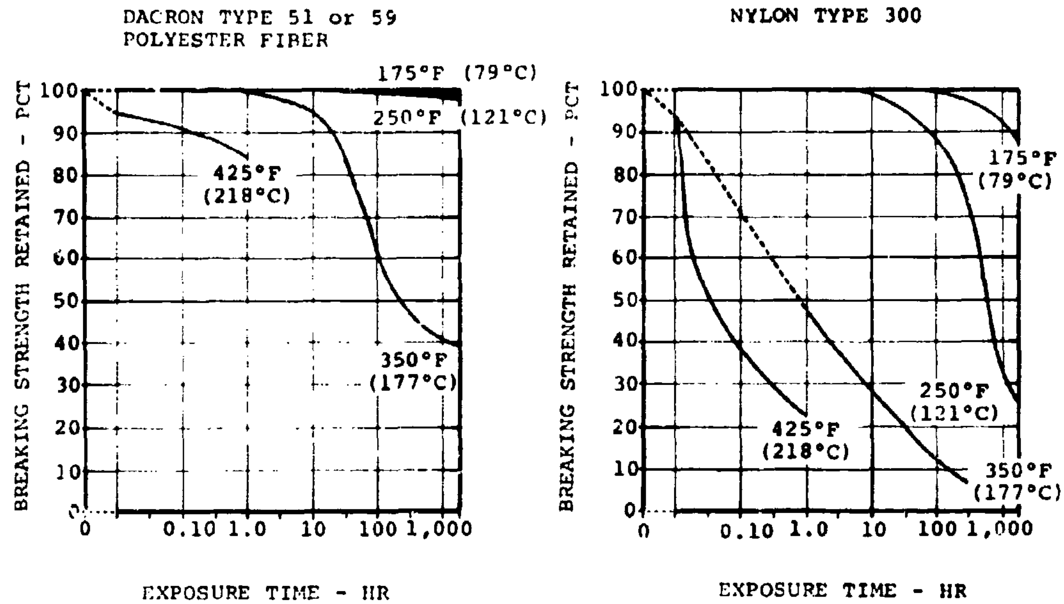


Figure 10. Heat Exposure Effects on the Strength of Dacron and Nylon Fibers.[6]

range. This phenomenon is of practical significance since ordinary window glass will not transmit the shorter wavelengths of ultraviolet light, and different sources of light will exhibit wide variations in spectral distribution and intensity.

Sunlight is the chief form of radiation and the most common cause for light deterioration of fiber products. The spectral distribution of sunlight at the earth's surface is about 5 percent in the ultraviolet region, 40 percent in the visible region, and 55 percent in the infrared region. Since window glass filters out the shorter wavelengths of ultraviolet light, radiation damage to fibers exposed under glass is less rapid than that of similar items exposed to direct sunlight. However, if heat is allowed to build up under the glass, the reverse may appear to be true because of the additional damage resulting from heat deterioration.

The relative loss of strength for Dacron and nylon yarns exposed to Florida sunshine and weather for 36 months is shown in Figure 11. The curves indicate that Dacron will retain a greater percentage of its original breaking

TABLE 3. HIGH-TEMPERATURE EFFECTS ON STRENGTH AND ELONGATION FOR DACRON AND NYLON FIBERS[4]

Properties of Scoured Unexposed Fibers

	Dacron 220-50-5100 Yarn	Nylon 840-140-300 Yarn
Breaking Tenacity, grams per denier	6.12	7.61
Breaking Elongation, percent	19.9	25.9
Initial Stretch Resistance, g.p.d. for 1.0 percent Stretch	0.97	0.41
Toughness (work to break), g.cm/d.cm	0.65	0.70
Average Denier per Filament	4.43	5.80

	Percent Strength Retained After Exposure		Percent Elongation Retained After Exposure	
	Dacron 220-50-5100	Nylon 840-140-300	Dacron 220-50-5100	Nylon 840-140-300
Control - No Exposure	100	100	100	100
Air, 250°F - 1 Hour	106	102	107	101
- 10 Hours	106	102	115	103
- 100 Hours	107	69	123	74
- 1000 Hours	93	33	121	38
Air, 300°F - 0.1 Hour	108	101	128	109
- 1 Hour	92	91	122	106
- 10 Hours	113	60	138	75
- 100 Hours	77	38	107	43
- 1000 Hours	65	Degraded	112	Degraded
Air, 350°F - 0.1 Hour	113	102	145	108
- 1 Hour	106	61	165	80
- 100 Hours	88	21	148	24
Air, 380°F - 1 Hour	100	42	159	53
Air, 400°F - 0.001 Hour	111	105	104	109
- 0.01 Hour	111	102	120	96
- 0.1 Hour	115	86	175	85
- 1 Hour	92	38	146	50
Air, 430°F - 0.01 Hour	111	102	112	106
Nitrogen, 300°F - 1 Hour	111	102	128	118
400°F - 1 Hour	105	95	183	123
Water, 210°F - 1 Hour	108	101	96	98
- 1000 Hours	27	76	16	90
Water, 225°F - 1 Hour	108	98	105	[illegible]
- 10 Hours	99	97	118	106
- 100 Hours	79	96	87	108
- 1000 Hours	20	79	8	90
Water, 250°F - 1 Hour	105	100	134	112
- 10 Hours	111	82	121	91
- 100 Hours	80	75	105	82
- 1000 Hours	Degraded	37	Degraded	46
Water, 300°F - 1 Hour	116	96	151	129
- 1000 Hours	Degraded	Degraded	Degraded	Degraded
Steam, Saturated, 250°F - 1 Hour	111	102	128	104
Steam, Superheated 250°F - 1 Hour	93	101	142	105
(atm. pressure) 400°F - 1 Hour	46	56	143	68

TABLE 1. WEBBING TEMPERATURE TEST DATA[5]

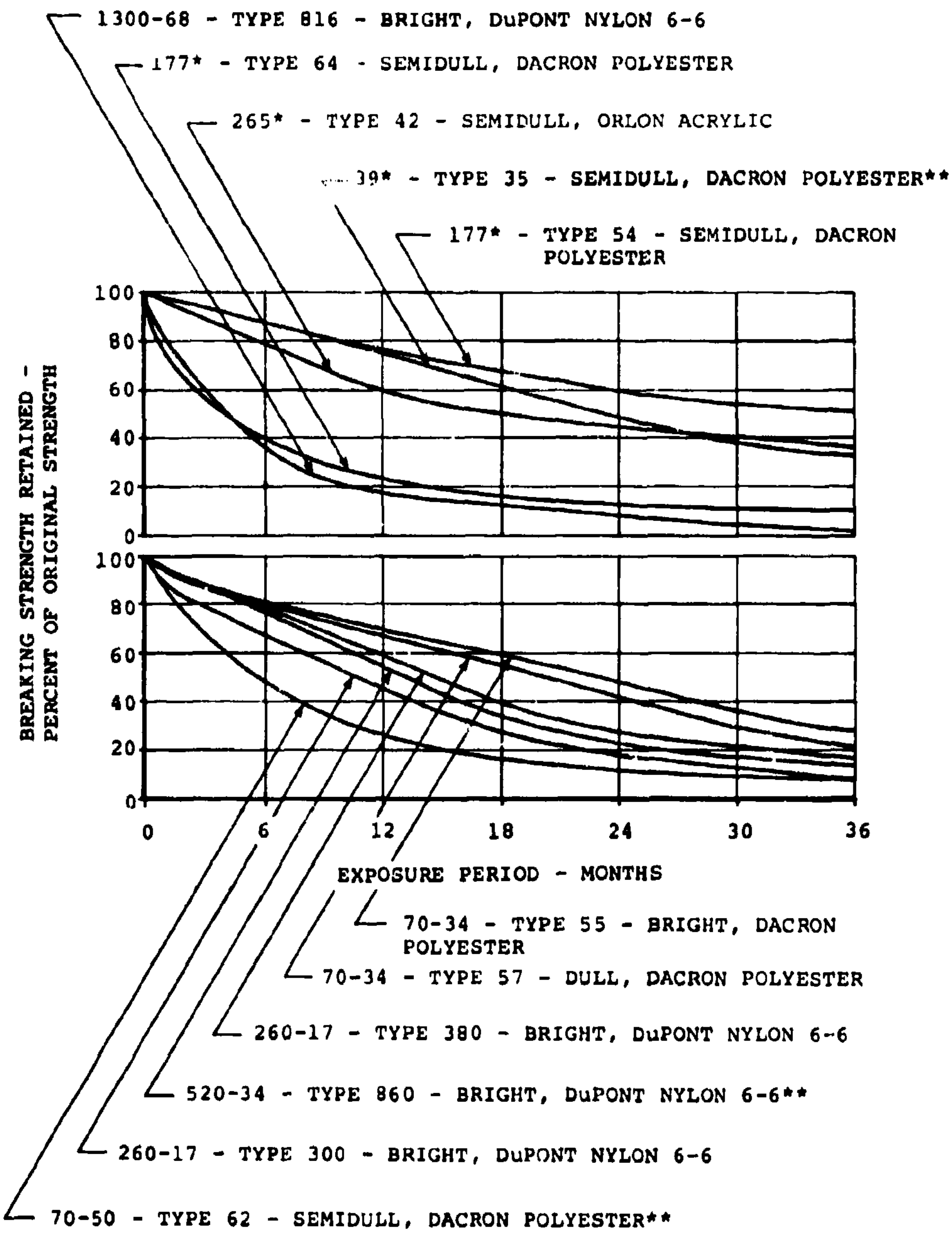
Webbing and Test (24 hr)	Failure Load (lb)	Failure Load Change (%)	Elongation (%)	Elongation Change (%)
Dacron (control)	5,210		15.6	
250°F	4,240	-18.6		
140°F*	5,220	+0.2	16.6	+6.4
-40°F*	5,200	-0.2	17.4	+11.5
-65°F	6,840	+31.3		
Nylon (control)	4,670		23.2	
250°F	3,750	-19.7		
140°F*	4,370	+1.3	26.2	+13.0
-40°F*	4,610	-1.3	24.8	+6.9
-65°F	5,650	+21.0		

*Tested at 70°F at 65 percent RH after 24-hour exposure to temperature.

strength than will nylon for a given exposure period. It also appears, from the data, that at the end of 36 months the highest percentage of strength retained for any Dacron yarn is 50 percent; however, it should be noted that the exposure conditions for the tests that generated these data were extremely severe. Test specimens were continuously under load and exposed to the weather and direct sunlight with only a single sheet of 1/8-inch clear window glass for protection. The deterioration during actual use of products made from these fibers should be much less than indicated by the data shown in Figure 11.

Webbing Service Life

The service life of a restraint system webbing should be the period of time expected for minimum deterioration of the webbing through normal use of the restraint. Webbing in use beyond its specified service life should be expected to show some deterioration of its restraint properties (i.e., strength and elongation). The service life of the webbing for the aircrew restraint system can only be estimated at this time since the webbing will be new and its aging characteristics will not have been exactly



Note: Denier equivalent for a filament yarn of glass fiber.
*Denier equivalent for a yarn spun from staple fibers.
**No direct exposures made.

Figure 11. Sun and Weather Effects on Breaking Strength of Dacron and Nylon Fibers.[8]

determined. However, the webbing will be made from a polyester fiber, and the previous environmental data indicate that polyester webbing should have a longer service life than the nylon webbing which is currently used in numerous restraint systems, both military and commercial.

A previous study[9] attempted to define a service life for seat belt webbings used in general aviation aircraft. Numerous seat belt configurations that included commercial and military systems were tested as specified in TSO-C22 (FAA Technical Standard Order). Seat belts with nylon and cotton webbing that varied in age from 0 to over 10 years were tested. The percentage of seat belts that failed to satisfy the requirements of TSO-C22 as a function of age is shown in Figure 12. From these data, it appears that 4 years is a reasonable service life for nylon webbing. Since it is expected that a polyester webbing would not deteriorate with age as much as nylon webbing, it is recommended that the service life of the nylon webbing for the aircrew restraint system initially be 5 years. After the restraint system is placed in service, periodic checks for webbing deterioration should be made and used to determine a more accurate service life for the webbing.

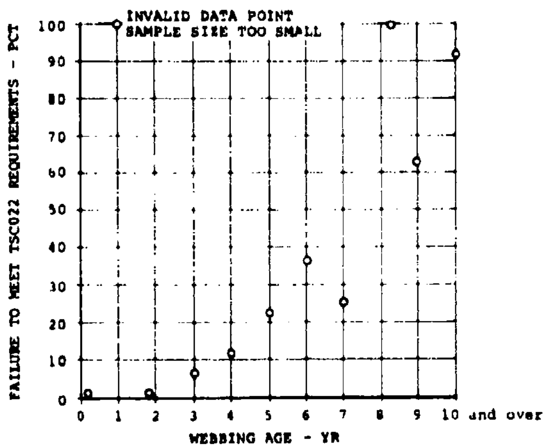


Figure 12. Webbing Failures as a Function of Age.[9]

9. INVESTIGATION OF SEAT BELT WEBBING SERVICE LIFE, Technical Report ADS-22, Federal Aviation Agency, Washington, D. C., September 1964.

RESTRAINT SYSTEM DESIGN

As a result of the analysis performed during the program, the configuration of the aircrew restraint system defined by the proposed military specification was changed to that shown in Figure 13.

The restraint system, designed to mount on an aircrewman's forward-facing seat, consists of one dual-spool inertia reel or two separate inertia reels with two reflected straps, a shoulder harness collar assembly, a lap belt assembly including retractors, and a buckle assembly. The buckle assembly consists of a single-point release buckle permanently attached to the tie-down strap. The tie-down strap consists of a fixed-length strap for any specific seat and cushion design and an anchor fitting that connects the strap to the seat pan beneath the seat cushion. The left- and right-hand lap belts, connected at the single-point release buckle, are attached to the seat or aircraft structure through automatic lock-unlock retractors. The shoulder harness collar assembly consists of a pad in the form of a collar, fitting around the crewman's neck, over which the shoulder harness straps are routed. The lower shoulder straps connect to the bottom of the collar assembly through the adjusters. The reflected straps pass through the roller fittings at the top of the collar. Each reflected strap is extended forward from an inertia reel, looped through the roller fitting, and then directed rearward to the opposite side of the seat back. These straps are attached to the seat through anchor fittings on the reflected ends and through inertia reels at the other end. The lap belt straps, tie-down strap, and lower shoulder straps are all connected at the single-point release buckle.

The aircrew restraint system as manufactured by Pacific Scientific Company, shown in Figure 14, consists of four major components.

- Inertia Reel Assembly (Items A, B, and C)
- Shoulder Harness Collar Assembly (Items D, E, F, and G)
- Lap Belt Assembly (Items H and I)
- Buckle Assembly (Items J, K, and L)

The total weight for an aircrew restraint system, as delivered to Dynamic Science, was 8.50 pounds. The distribution of this weight among the restraint system's assemblies is given in Table 5.

ITEM IDENTITY

1. BUCKLE ASSEMBLY
   A. SINGLE-POINT RELEASE BUCKLE
   B. TIE-DOWN STRAP
   C. TIE-DOWN ANCHOR

2. LAP BELT ASSEMBLY
   A. LAP BELT (LEFT- AND RIGHT-HAND)
   B. RETRACTOR

3. SHOULDER HARNESS COLLAR ASSEMBLY
   A. PAD
   B. ROLLER FITTING
   C. ADJUSTER
   D. LOWER SHOULDER STRAP

4 INERTIA REEL ASSEMBLY
   A. REFLECTED STRAP
   B. ANCHOR

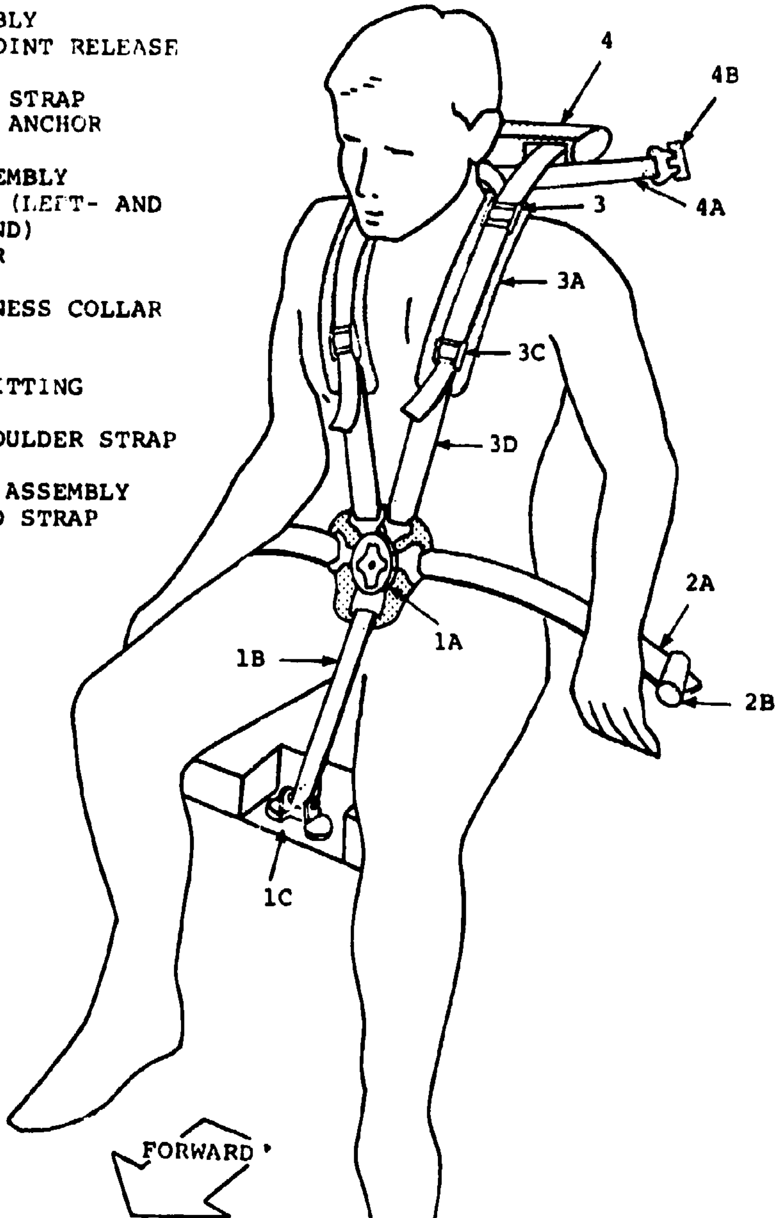
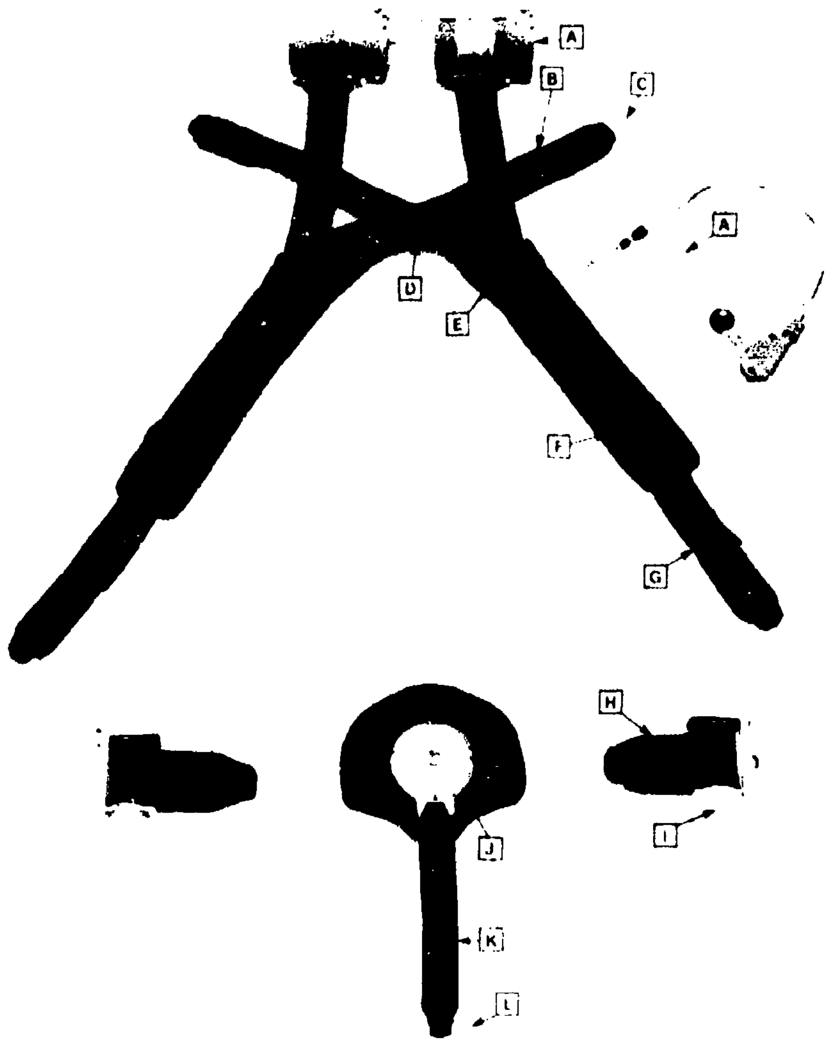


Figure 13. Restraint System, Aircrew, Forward-Facing.



A, B, C – Inertia Reel Assembly
D, E, F, G – Shoulder Harness Collar Assembly
H, I – Lap Belt Assembly
J, K, L – Buckle Assembly

Figure 14. PSCo's Aircrew Restraint System.

TABLE 5. RESTRAINT SYSTEM WEIGHT	
Restraint System Component	Weight (lb)
Inertia Reel Assembly*	3.59
Shoulder Harness Collar Assembly	1.54
Lap Belt Assembly	2.25
Buckle Assembly	1.12
Complete Restraint System	8.50

*Includes mounting bracket and control cable.

A complete description of each of the components of the aircrew restraint system is given in the following paragraphs. The letter designations mentioned in these descriptions refer to the items shown in Figure 14, while the part numbers correspond to PSCo drawings that are part of the design package. The webbing being used for the aircrew restraint systems is the special low-elongation polyester webbing developed during this program. Three webbing sizes are used; the physical properties for each are described in Table 6. The load-elongation curves for these webbing sizes are shown in Figure 6.

TABLE 6. WEBBING PROPERTIES

	Tie-down Strap	Shoulder Harness Straps	Lap Belt
Width (in.)	1.25	1.75	2.25
Thickness (in.)	0.043	0.047	0.043
Breaking Strength (lb)	4,366	6,740	7,620
Elongation (pct)	8.2	10.0	7.5
Elongation Load (lb)	2,500	4,000	4,000

INERTIA REEL ASSEMBLY

The inertia reel assembly (010692-01) consists of two inertia reels (MIL-R-8236 - Type MA-6, except for modifications) mounted on the same base (Item A) and having a common manual control cable and lever. Each inertia reel has a reflected strap (Item B) attached to its spool, with the other end terminated in an anchor fitting (Item C). The mounting base is designed for horizontal installation and includes two integral strap guides for directing the horizontal exit of the straps and for resisting strap side loads. The manual control cable attaches to a common lock lever located between the two inertia reels. The control lever is designed to mount on the left side of the seat pan. The control lever is used to put the inertia reel's locking mechanism in a manual lock or automatic lock mode and to reset the locking mechanism after the reel has automatically locked.

The total strap extension of each inertia reel is 32 inches, which, because of the reflected strap arrangement, permits 18 inches of upper torso movement for a 95th percentile crewman. Because there are two reel return springs, the tension force in each reflected strap is 2 pounds minimum and 5 pounds maximum instead of the 2- to 9-pound tension force currently specified for a Type MA-6 inertia reel. The reflected strap (Item B) is made from the 1.75-inch-wide low-elongation polyester webbing. The reflected strap anchor (Item C) is a small fitting that provides a slot for the reflected strap's webbing and a clevis for attaching the strap to the seat structure. The material used in the reflected strap anchor is 4130 steel, heat treated to 180 ksi minimum strength.

SHOULDER HARNESS COLLAR ASSEMBLY

The shoulder harness collar assembly (1107344-01) consists of a vinyl collar (Item D) that supports the roller fitting (Item E) and adjusters (Item F) through lengths of connecting webbing sewn on the vinyl collar. The lower shoulder straps (Item G) included in the assembly are threaded through the adjusters at the lower end of the collar; the reflected straps pass through the roller fittings at the upper end.

The collar pad (Item D) is a stitched assembly of a closed cell PVC plastic-nitrile rubber blended foam with a vinyl cover. A length of the 1.75-inch-wide low-elongation polyester webbing was sewn inside the collar to provide a strong load path between the roller fittings and the adjusters located on the opposite side of the collar. However, this length of webbing was subsequently deleted from the design because it would not conform to the collar's pattern and

consequently created wrinkling in the neck area of the collar that might have become extremely irritating to the occupant.

The roller fitting (Item E) provides a low-friction method of connecting the reflected strap to the lower shoulder strap while allowing easy withdrawal of the reflected strap from the inertia reel during movement of the occupant's upper torso. The roller fitting is connected to the adjuster through an 8-inch length of the 1.75-inch-wide low-elongation webbing that is overlapped and stitched to the pad, thereby attaching the roller fitting and adjuster to the collar. The overlapped webbing is sewn to the collar pad by a long boxed "W-W" stitch pattern. A 1-inch length of free webbing (webbing not stitched to the collar pad) provides a flexible joint that allows the roller fitting to align itself as the angle in the reflected strap changes.

The adjuster (Item F) permits the lower shoulder straps to be adjusted so that the fit of the shoulder harness collar matches the occupant. The strap length is adjusted by pulling a lift tab that rotates the locking cam away from the webbing, and then pulling the webbing, one way or the other, through the adjuster.

The lower shoulder strap (Item G) serves as the load-carrying member between the adjuster and the single-point release buckle. It consists of an 18-inch length of 1.75-inch-wide low-elongation polyester webbing with one end threaded through the adjuster and the other end equipped with a plug-in buckle fitting.

LAP BELT ASSEMBLY

The lap belt assembly (1106133-01) consists of two lap belts (Item H) and two retractors (Item I). The lap belts are 2.25-inch-wide low-elongation polyester webbing, with a metal tab for attaching the webbing to the retractor spool clamped on one end, and a buckle fitting that interfaces with the locking mechanism of the buckle stitched to the other end. The retractor is an automatic, lock-unlock type in which the webbing can be freely extended against a spring load to its full length. However, a motion stoppage locks the reel, and additional movement is possible only in a belt-tightening direction. Release of the locking mechanism is achieved by allowing the retractor to withdraw the lap belt webbing to the unlock length of 11.5 inches. The retractors provide a means for storing the lap belts as well as making their adjustment automatic. A movable guide mounted to the retractor's housing aligns the webbing on the spool. The retraction force generated by the retractor is between 7-1/2 and 15 pounds. The minimum retraction force

(7-1/2 pounds) is measured with the lap belt attached to the buckle without an occupant in the seat, while the maximum force (15 pounds) is measured with the lap belt fully withdrawn from the retractor.

BUCKLE ASSEMBLY

The buckle assembly (1107341-01) provides the connection and release provisions for all of the restraint systems's straps except for the tie-down strap which is permanently attached to the buckle. The buckle assembly includes a single-point release buckle with a pad, a tie-down strap, and a tie-down strap anchor.

The single-point release buckle (Item J) connects the two lower shoulder straps and the two lap belts to the tie-down strap permanently attached to the buckle. The buckle has a handle on the front face that contains four symmetrically placed vanes. This handle can be rotated in either direction to release the fittings. Positive ejection springs are incorporated within the buckle to ensure that fittings not fully withdrawn from the buckle during handle rotation do not become reengaged when the handle is released. A vinyl-covered PVC and nitrile rubber blended foam pad, which distributes and cushions the buckle load and increases comfort during normal usage, is attached to the back of the buckle.

The tie-down strap (Item K) consists of 1.25-inch-wide low-elongation polyester webbing that is permanently attached to the single-point release buckle on one end and to the tie-down strap anchor on the other. The purpose of the tie-down strap is to prevent the lap belt from being pulled up by the shoulder straps, thereby permitting the occupant to "submarine" under the lap belt. The tie-down strap anchor connects the tie-down strap to the seat. The anchor is a suitcase handle type of fitting and is fabricated from 4130 steel, 0.625 diameter stock, heat treated to 180 ksi minimum strength. The webbing loops around the center section and two 0.25-inch-diameter holes for attaching it to the seat pan are located in the tabs of the anchor. The design of the tie-down anchor was changed during the program because of a failure during the dynamic tests, (see Dynamic Tests). The first tie-down anchor was a bent fitting that contained a slot for the webbing and two 0.25-inch diameter holes for attaching it to the seat pan. The anchor has a 60-degree bend to properly orient the strap and is fabricated from 0.125-inch-thick 4130 steel sheet, heat treated to 180 ksi minimum strength.

RESTRAINT SYSTEM FABRICATION

Five complete aircrew restraint systems were manufactured and assembled by Pacific Scientific Company. These restraint systems were then delivered to Dynamic Science and subjected to all of the tests required by the proposed specification. In addition to manufacturing the parts necessary to assemble the restraint systems, PSCo also built extra hardware components that were destructively tested to determine the failure load and mechanism of each metallic element in the restraint system.

The restraint system's components were fabricated in accordance with the approved design except for minor changes in the single-point release buckle and the webbing straps.

SINGLE-POINT RELEASE BUCKLE

During the fabrication task, the entry angle of the lap belt fitting, previously determined to be 20 degrees, was reexamined. Some preliminary testing by PSCo had indicated that severe in-plane bending of the fittings would occur if the strap design loads were all simultaneously applied to the buckle.

The 20-degree entry angle had been selected, based on mock-up tests discussed previously, to enhance the normal operation of the restraint system and to improve the initial loading conditions at the buckle. When the harness is loaded, however, it is evident from the available test data that the lap belt fitting angle decreases, which tends to rotate buckle fittings toward the horizontal centerline of the buckle. This is caused by movement of the buckle when an occupant is subjected to a longitudinal deceleration; the buckle's path is along a circular arc whose radius is the length of the tie-down strap. As the occupant moves forward and loads the restraint system, the shoulder harness exerts a force on the buckle, causing it to move up and forward from its initial position. At the same time, the angle at which the lap belt load is applied to the buckle decreases because of the buckle's motion in relation to the lap belt. This angle apparently passes through and below the horizontal centerline of the buckle, since measured data indicate that the tie-down strap load never completely balances the shoulder harness load.

To be compatible with this changing angle, an ideal fitting attachment at the buckle would be one that allowed the fitting to rotate within the plane of the buckle. A fixed fitting attachment such as PSCo's, which could not rotate and thereby align itself with the lap belt load, was felt to be satisfactory provided that a nominal entry angle not detracting from the performance of the restraint system could be determined.

To establish this angle, PSCo conducted several fitting tests with occupants of two different sizes. Two mock-up restraint systems were fitted to a test seat and tested for fit by 5th and 95th percentile (weight) subjects. Both systems used the length and position of the F111 restraint harness tie-down strap. One system used the buckle with the lap belt fitting offset 20 degrees, and the other system used the standard buckle with straight fittings. The former configuration showed no particular comfort attributes, and there was some potential for fitting/thigh interference. Based on the results of these tests, PSCo suggested an entry angle of 0 degrees as the best angle for a fixed fitting.

It was subsequently decided that an optimum fitting should rotate in the plane of the buckle, and the initial entry angle for such a fitting should remain at 20 degrees with respect to the horizontal centerline; but a fixed fitting with an entry angle of 0 degrees was an acceptable substitute provided it could withstand the loads imposed during the dynamic tests. The proposed specification was therefore formulated to allow either type of buckle-fitting attachment (rotary or fixed). The buckles supplied by PSCo for this program had fixed fitting attachments with a lap belt entry angle of 0 degrees.

The new prototype buckles were then fabricated using a flat load plate with the lap belt plug-in fitting sockets on the horizontal centerline and the tie-down strap fitting socket located 90 degrees below, or on the vertical centerline. The shoulder strap fitting sockets are located above the buckle's center and are positioned symmetrically about the vertical centerline. All fitting ends are supported by one continuous ring that reacts their out-of-plane bending loads. A cutaway view of the buckle, illustrating the interface between the buckle fittings and the latch dogs, is shown in Figure 15. Ejector springs were installed to prevent the dogs from re-engaging the fittings when they are not fully withdrawn at the time of handle rotation.

WEBBING STRAPS

The thread size and stitch patterns used to sew the webbing joints of the aircrew restraint system were also examined during fabrication, and it was decided to change the thread size in the proposed specification from Number 6 nylon cord (per Federal Specification V-T-295a) to Number 4 nylon cord. The basic reasoning behind this change was that it is very difficult to sew Number 6 nylon cord in a tight, continuous stitch pattern. This creates the possibility of having loose stitches in the pattern which would lower the strength of the webbing joint and defeat the advantage of using the high

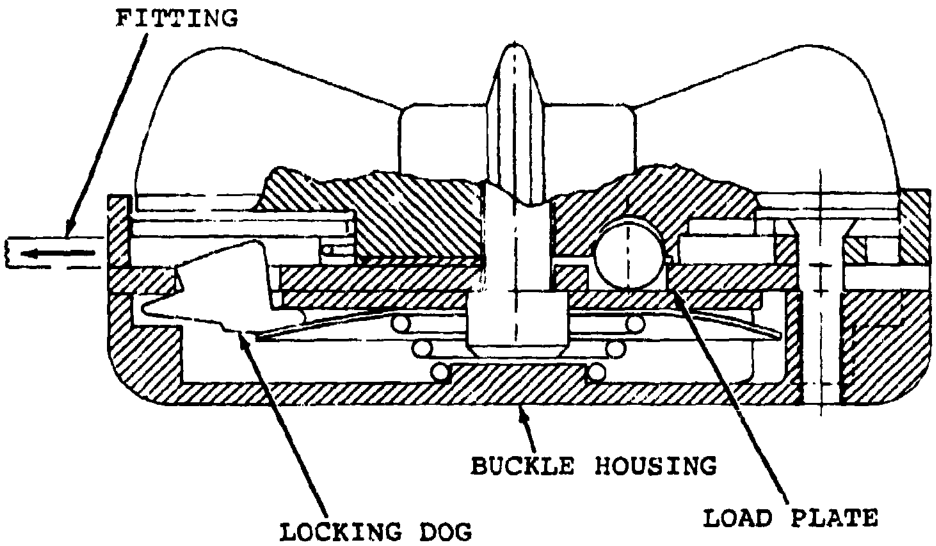


Figure 15. Section View of Buckle Showing Locking Dog and Its Retention Interface.

-strength Number 6 nylon cord. Number 4 nylon cord has a lower breaking strength (32 pounds for Number 4 versus 50 pounds for Number 6), but it is easier to sew in a quality stitch pattern and, therfore, was chosen as the thread size for the five aircrew restraint systems fabricated.

After making the change to Number 4 cord, which is a standard cord listed in the literature, procurement efforts were unsuccessful. According to a leading thread company, Number 4 thread is not available in the United States today. Subsequently, it was decided to use Number 3 nylon thread, which was available. Number 3 cord has a breaking strength of 24 pounds, and the stitch patterns for the webbing joints were redesigned for the Number 3 nylon thread.

The seam strength for a series of straight stitches was determined by multiplying 80 percent of the thread strength by the number of stitches in the seam. For the Number 3 nylon thread, 9 stitches per inch provides a seam strength for a single lap joint of 173 pounds per inch, which is comparable to a seam strength of 180 pounds per inch that 4-1/2 stitches per inch of Number 6 nylon thread would provide for the same type of

webbing joint. Using the loop joint seam strength for Number 3 nylon thread (346 pounds per inch) and either 4- or 5-point "W-W" stitch patterns, depending on the width of the webbing, the following stitch patterns for each webbing joint and their minimum lengths were determined:

- Tie-down Strap

  Stitch Pattern - 4-point "W-W"

  Minimum Length - 1-3/8 inches

- Lower Shoulder Strap

  Stitch Pattern - 4-point "W-W"

  Minimum Length - 2-3/16 inches

- Reflected Strap

  Stitch Pattern - 4-point "W-W"

  Minimum Length - 1-3/32 inches

- Lap Belt

  Stitch Pattern - 5-point "W-W"

  Minimum Length - 1-3/4 inches

These lengths were based on the design load of the webbing and included a 50-percent increase in the total stitch length to offset the loss of strength due to age and wear.

To determine the actual stitch patterns that could be sewn by PSCo, it was necessary to establish what thread would produce the strongest and, at the same time, the best quality stitched joint. The largest thread in production usage at PSCo is size "FF" nylon per Federal Specification V-T-295a. This has a 16-pound breaking strength compared to 24 pounds for Number 3, 32 pounds for Number 4, and 50 pounds for Number 6. As previously mentioned, the largest thread below Number 6 that was available at this time was Number 3.

At PSCo, two types of sewing machines are used. One is a heavy-duty hand-guided machine; the stitch pattern is determined by the capability of the operator to follow layout lines drawn on the material. The other machine has the pattern programmed by a cam drive, and the operator controls only the location of the pattern on the material. Obviously, the latter

is much more efficient to use and produces a consistent pattern at a much faster rate; however, only production patterns have been adapted to this machine, and they cannot be readily changed.

The PSCo production stitch patterns are known as "W-W" and boxes. The "W-W" is always 1.75 inches long and is available in two widths: 1.38 inches for 1.75-inch webbing and 1.56 inches for 2.0-inch webbing. Each pattern has a 0.25-inch-long box overlapped across the end. There is also a 0.37-inch x 1.56-inch box pattern used individually.

In order to ensure ample joint strength and to provide an extra margin for harness aging, PSCo experimentally determined the stitch patterns. Because of the shortage of the 1.75-inch-wide special webbing used in the restraint systems, preliminary testing for this width webbing was done with 1.75-inch-wide by 0.75-inch-thick webbing that was readily available (Type II per MIL-W-25361). After each pattern was developed, it was verified with the required 1.75-inch-wide by 0.047-inch-thick special low-elongation webbing. The stitched joints used on the aircrew restraint systems delivered to Dynamic Science were:

- <u>Tie-down Strap - 1.25-inch-wide webbing</u>

  The stitch pattern was a 1.00-inch-wide by 2.00-inch-long "W-W" overlapped by a 0.25-inch-long box. The total length was 2.00 inches. This was a special size because of the narrow webbing and was not a cam-guided pattern.

- <u>Lower Shoulder Strap - 1.75-inch-wide webbing</u>

  The stitch pattern was made up of two 1.38-inch-wide by 1.75-inch-long "W-W's" facing each other and overlapped by two 0.25-inch-long boxes. The total length was 2.50 inches.

- <u>Reflected Strap - 1.75-inch-wide webbing</u>

  The stitch pattern was one 1.38-inch-wide by 1.75-inch-long "W-W" overlapped by a 0.25-inch-long box. The total length was 1.75 inches.

- <u>Lap Belt - 2.25-inch-wide webbing</u>

  The stitch pattern was made up of two pairs of 1.56-inch-wide by 1.75-inch-long "W-W's" overlapped with 0.25-inch-long boxes which were distributed across the

webbing width, staggered to minimize overlap, and facing each other. The total length was 3.50 inches.

(Note: All stitch patterns used Number 3 nylon thread per Federal Specification V-T-295a, and all webbing joints had three layers of webbing.)

TEST FIXTURES

The fixtures used to perform the static tests called for by the proposed specification were fabricated in accordance with the approved designs. The assembly drawings for these fixtures are presented in Appendix A. The test fixtures were designed to be easily adaptable to the variety of tests that were required, and each device had bolt-on adapters that provided attachment provisions for several restraint components. The Static Test Fixture (DSL602) was used to perform the strength and elongation tests, while the Functional Test Fixture (DSL603) was used for most of the tests designed to evaluate the operational and wear characteristics of the restraint system's components. For the buckle release tests, both the Torque Fixture (DSL604) and the Static Test Fixture were required. The Tensile Test Fixture (DSL605) was used with a universal testing machine for the tie-down strap strength and elongation test.

STATIC TEST FIXTURE

The Static Test Fixture (DSL602) was designed to apply tension loads of different magnitudes to the restraint system's subassemblies and components. These loads were applied by three hydraulic cylinders attached to an I-beam frame. The hydraulic cylinders were double-acting cylinders with 17,670 pounds maximum pushing force and 9,820 pounds maximum pulling force. Load cells were placed between the cylinder rods and the test articles to measure the loads that were applied. The Static Test Fixture was used for:

- Lap Belt Assembly Test
- Shoulder Harness Test
- Buckle Release Test

For the buckle release test, the Torque Fixture was used in addition to the Static Test Fixture.

The basic structure of the Static Test Fixture consisted of steel I-beams (AISI W6X12) that formed two orthogonal load-carrying members, as illustrated in Figure 16. Two hydraulic cylinders, placed at each end of the lateral beam (DSL602-17), were used to apply the lap belt loads while keeping the buckle located on the centerline of the fixture. The third hydraulic cylinder, located on the longitudinal beam (DSL602-13), was used to apply the tie-down strap and shoulder harness loads. The anchor plate (DSL602-19) and the angles (DSL602-11) supplied the mounting provisions for all of the required test

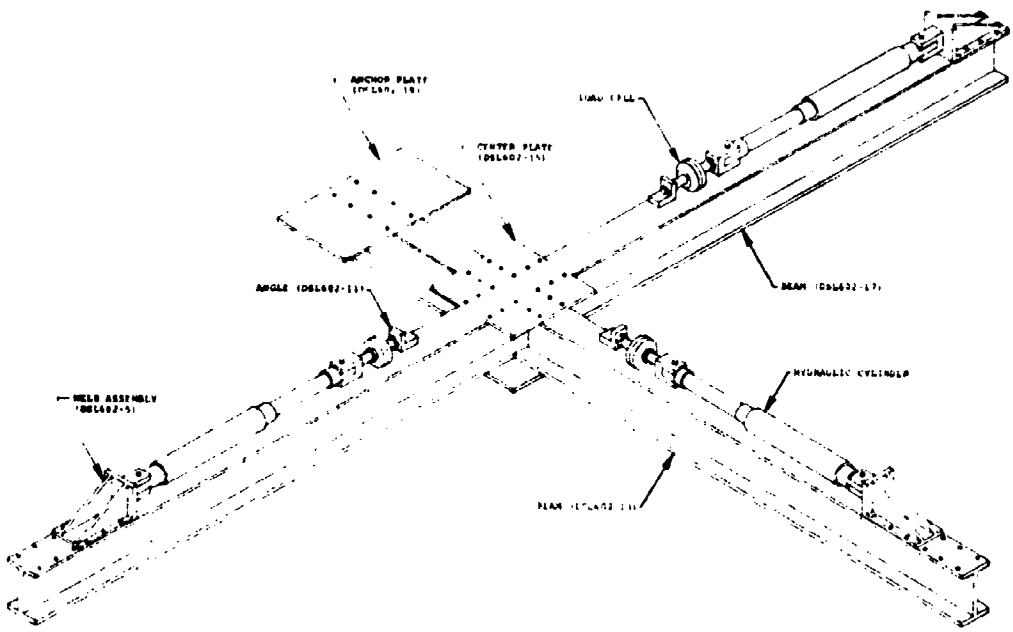


Figure 16. Static Test Fixture.

setups. The Static Test Fixture can be easily disassembled for storage or shipping by removing the center plate (DSL602-15), which is bolted to the two I-beam members.

FUNCTIONAL TEST FIXTURE

The Functional Test Fixture (DSL603) is a crank-driven slider mechanism that provides the back-and-forth motion required for testing several components of the restraint system. The Functional Test Fixture was used for:

- Retractor Extension Load Test
- Retractor Locking Test
- Adjuster Load Test
- Adjuster Webbing Abrasion Test
- Roller Fitting Test

The power source for the Functional Test Fixture was a 1/2-hp DC motor (shunt wound) connected to a 30-to-1 worm gear speed reducer. The speed reducer's output shaft was coupled to an

electric clutch-brake which in turn was connected by a shaft (DSL603-23) to the crank (DSL603-21). One of two connecting rods (DSL603-19 or DSL603-37), depending on the range of motion required for the test, was used to connect the crank to the traveler base (DSL603-17), whose motion was guided by the guide channel (DSL603-11). This mechanism is illustrated in Figure 17.

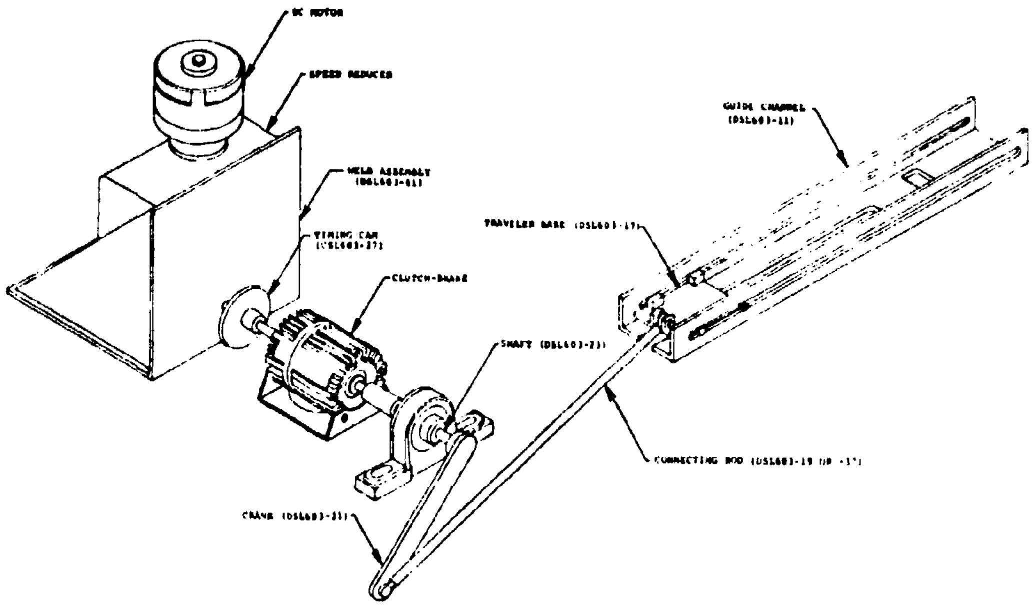


Figure 17. Functional Test Fixture.

The power requirements for the Functional Test Fixture were established by determining the maximum output torque and speed needed for the various tests, and then using manufacturer's performance tables to select the power drive components. The maximum torque required was approximately 200 inch-pounds, which was needed for the retractor locking test. The torque available from the 1/2-hp DC motor with the 30-to-1 speed reducer was 295 inch-pounds, which provided a minimum torque reserve of 32 percent. A gear reducer with an output range of 58 to 2 rpm was selected to provide maximum flexibility since an operating rpm of 3.3 was required for one series of tests and 50 rpm was required for another. The motor's rpm was governed by a variable transformer-type speed control, making it possible to continuously adjust the motor's speed as well as reverse its direction. Timing signals for activating the

clutch-brake were supplied by a limit switch activated by the timing cam (DSL603-27) attached to the gear reducer's output shaft.

TORQUE FIXTURE

The Torque Fixture (DSL604) was used with the Static Test Fixture as shown in Figure 18 to actuate the buckle and to measure the release data for the buckle release test. The Torque Fixture provided the torque necessary to actuate the buckle while the restraint system was subjected to a simulated 1G load, applied by the Static Test Fixture. In addition, it also measured the torque at which the buckle fittings released, and at what angle or angles of handle rotation the releases occurred. The release data were obtained from a 0- to 1000-inch-ounce torque cell and a precision potentiometer, which was chain driven from a sprocket attached to the top of the torque cell. The sprocket ratio from the torque cell to the potentiometer was 8-to-1, permitting an increase in the number of turns on the potentiometer during the buckle release sequence, thereby improving the resolution of the rotation angle measurement. The torque was generated and transferred by the same DC motor, speed reducer, and clutch-brake that were used on the Functional Test Fixture. For the buckle release tests, the output speed from the gear reducer was set at 3.3 revolutions per minute.

TENSILE TEST FIXTURE

The Tensile Test Fixture (DSL605) illustrated in Figure 19 was used as an adapter to a universal testing machine to test the tie-down strap assembly. The lower section (DSL605-1) of the fixture provided the 30-degree orientation for the tie-down strap anchor, while the top section (DSL605-3) was used to hold the buckle in place with two shoulder strap fittings.

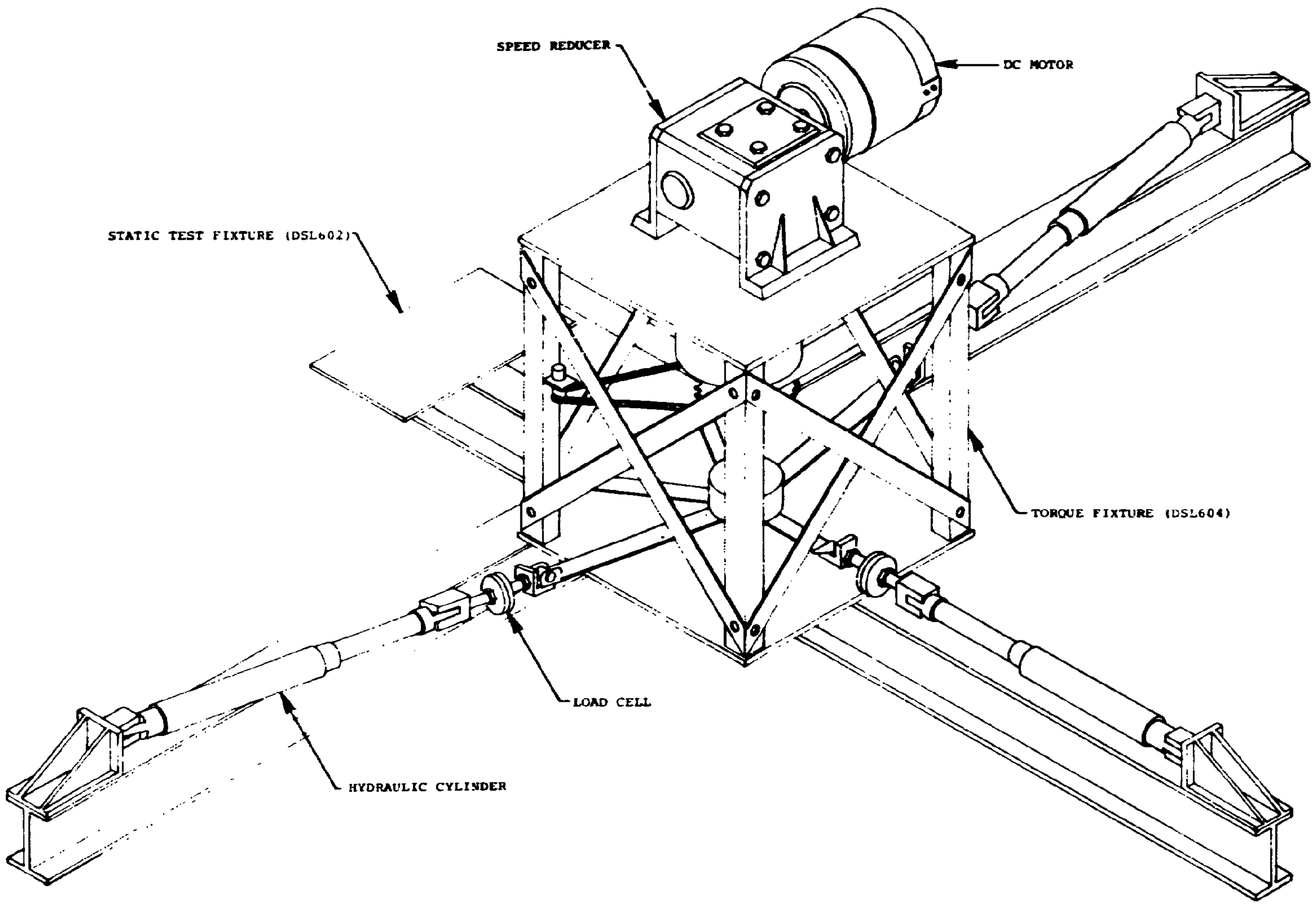


Figure 18. Torque Fixture.

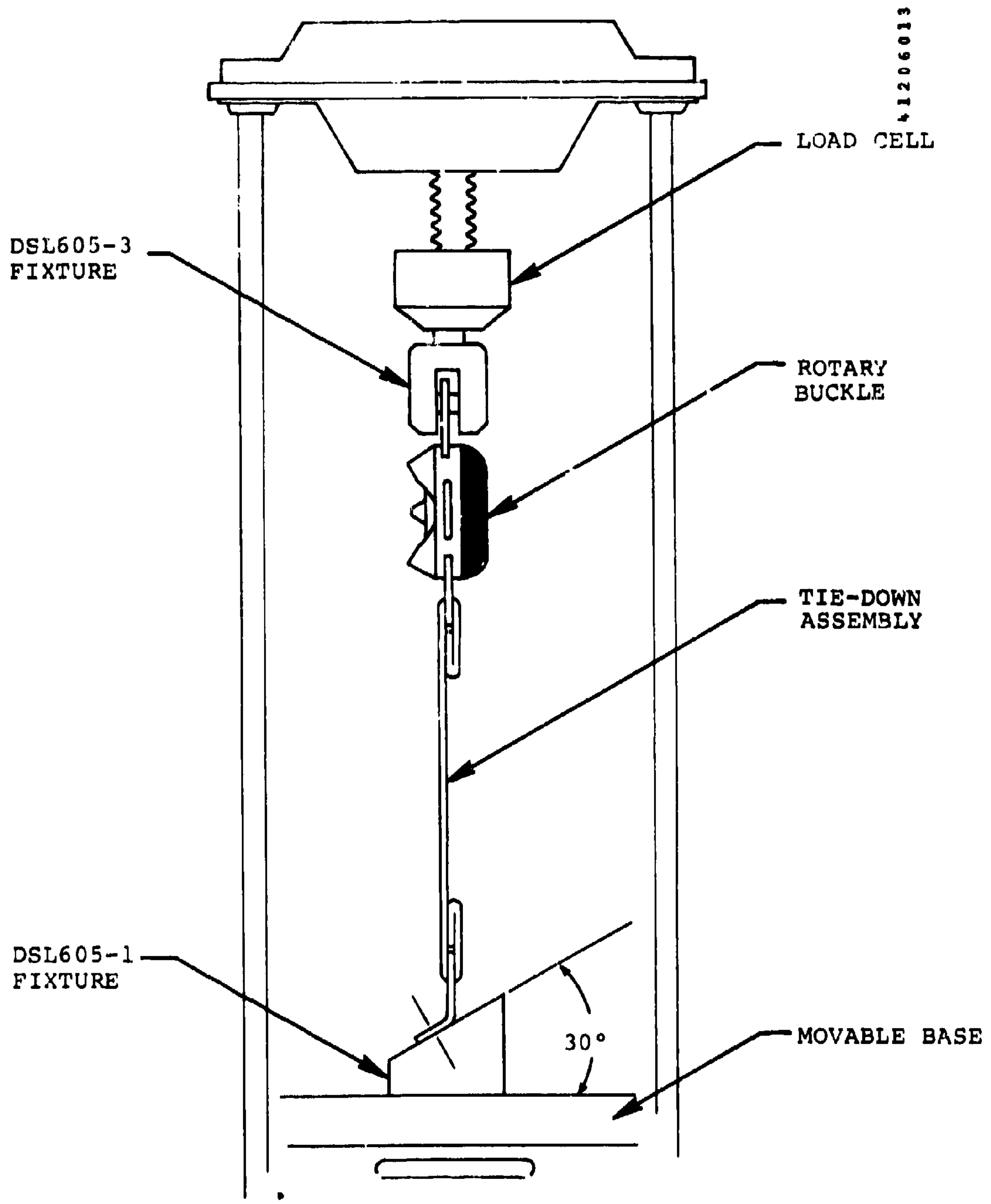


Figure 19. Tensile Test Fixture.

STATIC TESTS

Three of the aircrew restraint systems received from Pacific Scientific Company were statically tested to verify their capability of meeting the static test part of the quality assurance provisions of the proposed specification. The tests were conducted on components and subassemblies of the restraint system to ensure that efficient restraint can be provided during a 95th percentile light fixed- or rotary-wing aircraft accident, as defined in USAAMRDL TR 71-22, and that normal operating characteristics of the restraint system meet or surpass the specification's requirements.

The static tests were set up to be conducted on the components and subassemblies of a delivered restraint system using a tensile test machine and the special test fixtures previously discussed. With the exception of the webbing tests, no special pieces of restraint system hardware were required for any of the tests.

Ten static tests were conducted on components and subassemblies of the aircrew restraint system. These tests could generally be described as either strength tests or operational tests. The strength tests were conducted on

- Webbing
- Lap Belt Assembly
- Shoulder Harness Assembly
- Tie-Down Strap
- Hardware Components

to ensure that the strength and elongation requirements of the specification were satisfied and to determine the failure load and failure mode of each of these components. The operational tests were conducted on

- Retractor
- Adjuster
- Roller Fitting
- Inertia Reel
- Buckle

to ensure that each of these components would operate properly over the expected life of the restraint system and, in the case of the buckle, after being subjected to simulated crash loads.

WEBBING TESTS

The purpose of the webbing tests was to verify that the elongations of the three webbings used in the restraint system were equal to or less than those specified by the webbing supplier, and that the ultimate strengths of the webbings were greater than or equal to the minimum ultimate strengths shown in Table 7.

TABLE 7. WEBBING DIMENSIONS AND MINIMUM ULTIMATE STRENGTH

Component	Width (in. ±1/16)	Thickness (in. ±.010)	Minimum Ultimate Strength (lb)
Tie-down Strap	1-1/4	0.045	4,000
Lap Belt	2-1/4	0.046	5,000
Lower Shoulder Straps Collar Assembly Reflected Straps	1-3/4	0.045	6,000

Three webbing tests, one for each webbing size, were conducted. The test specimen in each of these tests was a single 54-inch length of webbing. The webbing length was gripped with webbing test jaws complying with Method 4108.1 of Federal Test Method Standard 191. The jaws were placed in a universal testing machine as shown in Figure 20. The gauge length of webbing over which the elongation was measured was 5 inches, marked on the webbing so that with the webbing specimen mounted in the test jaws, neither mark was closer than 1-1/2 inches to the clamps. The test jaws were then separated at a rate of 0.75 inch per minute, and the elongation of the webbing gauge length, as a function of applied load, was incrementally recorded at 500-pound intervals. The test jaws were momentarily stopped for each elongation measurement, which consisted of a visual reading of the gauge length from a handheld scale. These readings were recorded simultaneously with the force readings visually taken from an SR4 strain indicator. The elongation was specifically measured at the design load of the

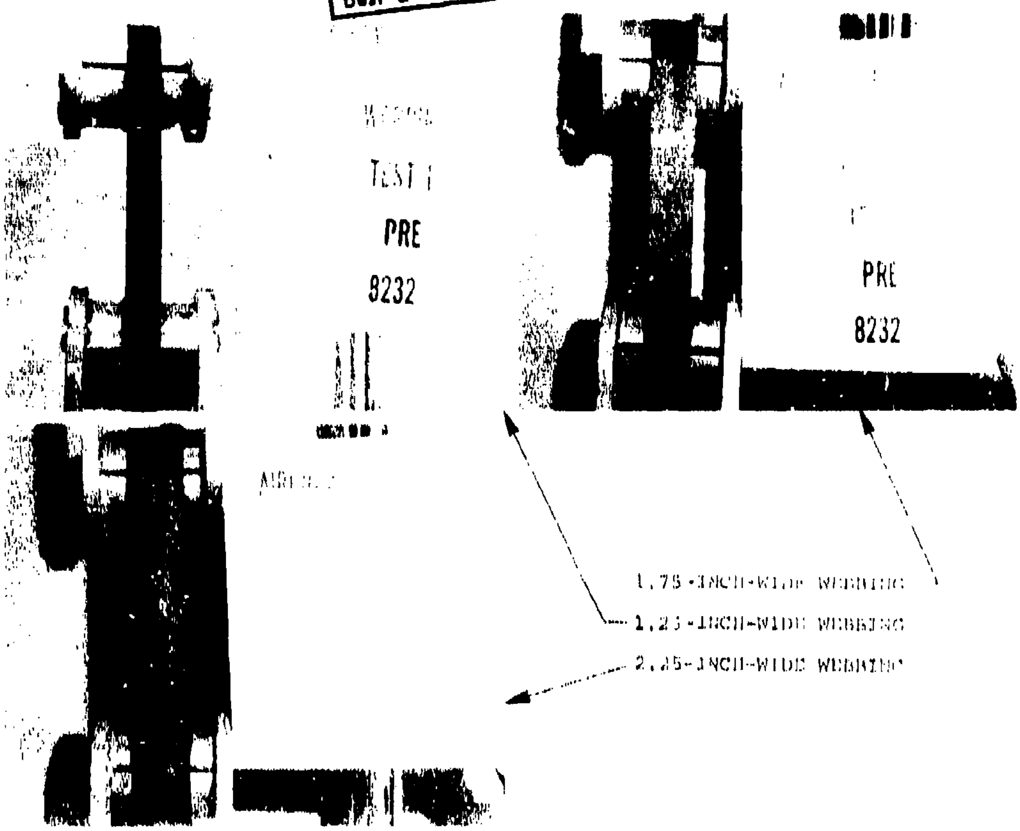


Figure 20. Webbing Test Configurations.

webbing. Testing continued until the webbing failed. The failures that resulted are shown in Figure 21. The load-versus-elongation data are shown in tabular form in Table 8 and graphically in Figure 22.

All three webbing sizes failed at loads that were higher than their minimum ultimate strengths, and their elongations at the webbing design loads were compatible with those specified by the manufacturer. The 1.25-inch-wide webbing failed at 4,250 pounds ±10 percent and had an elongation of 8.4 percent at 2,500 pounds. The principal failure occurred laterally across the webbing (see Figure 21) and with fibers separating within a 4-inch length of webbing. Failure of the 1.75-inch-wide webbing occurred at 6,250 pounds ±10 percent, and the elongation at 4,000 pounds was 10.8 percent. Fiber separation occurred diagonally across the webbing over a length of 17 inches, as

1.25-INCH-
WIDE
WEBBING

[illegible]-INCH-
WIDE
WEBBING

2.25-INCH-
WIDE
WEBBING

Figure 21. Webbing Failures.

TABLE 8. WEBBING ELONGATION DATA

Load (lb)	Elongation of 1.25-Inch-Wide Webbing		Elongation of 1.75-Inch-Wide Webbing		Elongation of 2.25-Inch-Wide Webbing	
	Inch	Percent	Inch	Percent	Inch	Percent
100 Preload	5.00	0	5.00	0	5.00	0
500	5.03	0.6	5.05	1.0	5.03	0.6
1,000	5.18	3.6	5.14	2.8	5.08	1.6
1,500	5.29	5.8	5.28	5.6	5.19	3.8
2,000	5.35	7.0	5.33	6.6	5.28	5.6
2,500	5.42	8.4*	5.39	7.8	5.32	6.4
3,000	5.50	10.0	5.45	9.0	5.37	7.4
3,500	5.60	12.0	5.49	9.8	5.42	8.4
4,000	5.70	14.00	5.54	10.8*	5.47	9.4*
4,500	Failure 4250 lb		5.60	12.0	5.51	10.2
5,000			5.64	12.8	5.56	11.2
5,500			5.72	14.4	5.60	12.0
6,000			5.78	15.6	5.66	13.2
6,500			Failure 6250 lb		5.71	14.2
7,000					5.76	15.2
					Failure 7250 lb	

*Design Load Elongati

shown in Figure 21. The 2.25-inch-wide webbing failed at 7,250 pounds ±10 percent, and its elongation at 4,000 pounds was 9.4 percent. The failure pattern was a V-shaped tear starting at the center of the webbing and extending diagonally out to the webbing's edges (see Figure 21), with complete fiber separation occurring over a 10-inch length of webbing.

LAP BELT ASSEMBLY TEST

The purpose of the lap belt assembly test was to demonstrate that the lap belt assembly could withstand the design load of 4,000 pounds, to establish its elongation at the design load, and to determine its ultimate strength.

A right- and a left-hand lap belt assembly, with a single-point release buckle, were mounted in the Static Test Fixture (DSL602) as shown in Figure 23 and were adjusted to the length required

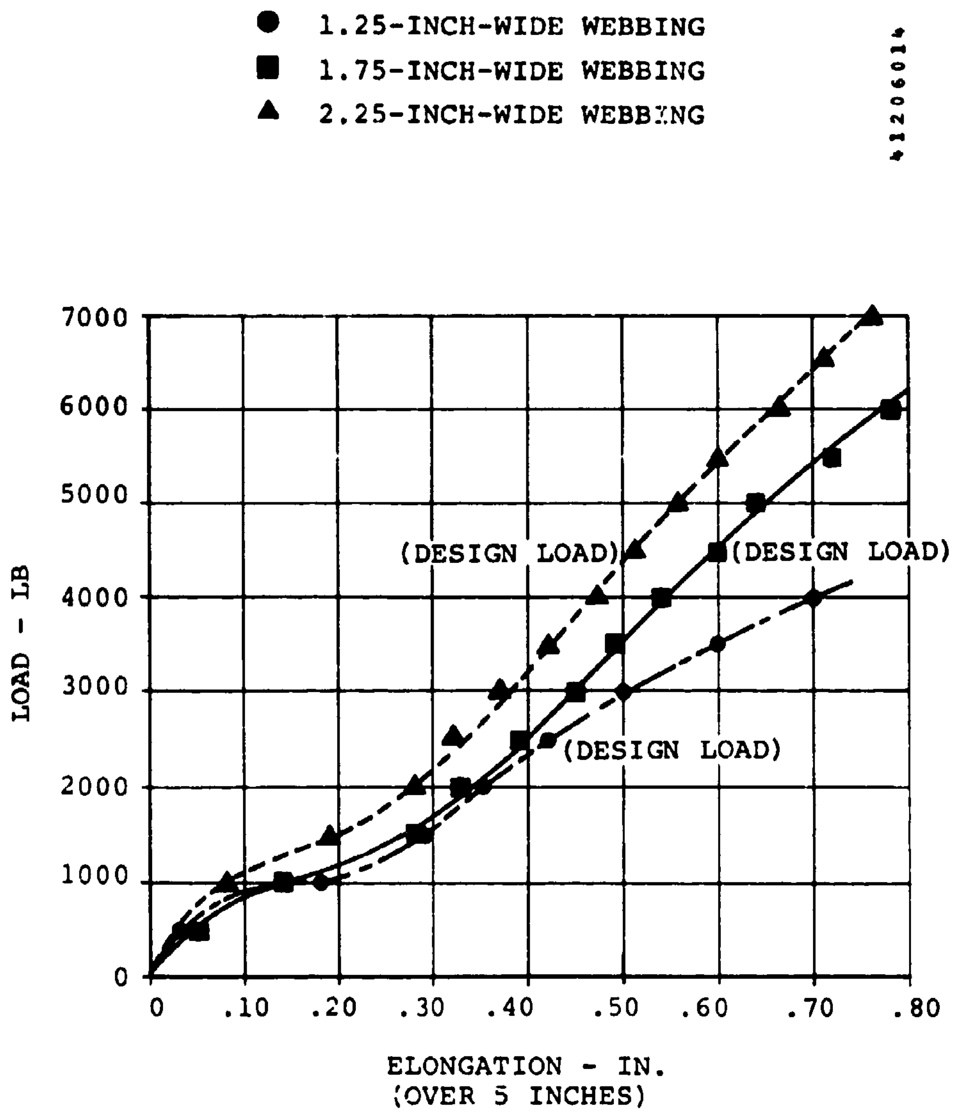


Figure 22. Webbing Elongation Data.

to fit a 95th percentile occupant. The initial length between retractors was 41 inches, with equal amounts of webbing taken from each retractor. After an initial preload of 100 pounds had been applied, pointers were fixed to the webbing at two locations (next to each retractor) to measure both total elongation and elongation of the webbing outside the retractor housing. The assembly was then loaded until failure occurred,

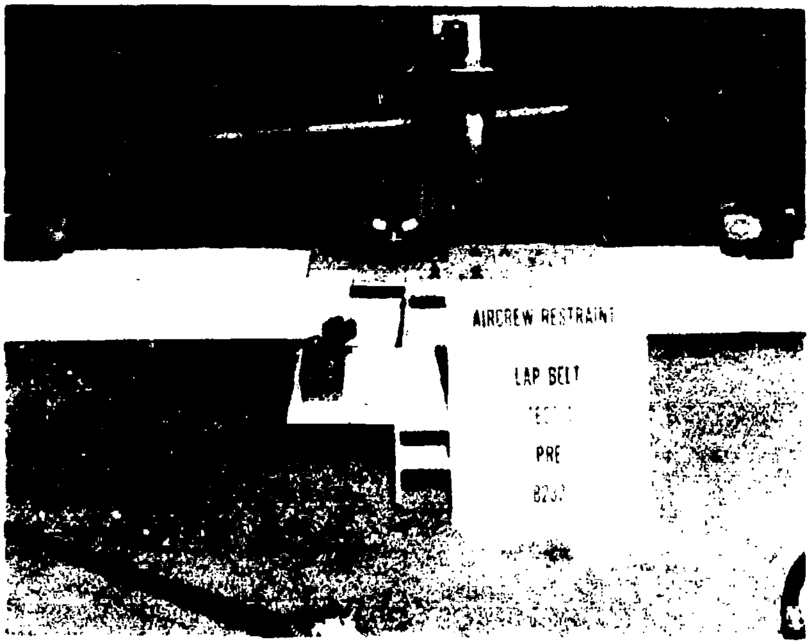


Figure 23. Lap Belt Assembly - Pretest.

with the elongation measured at each 500-pound increment. The load was applied by the hydraulic cylinder attached to the right lap belt, which means that the right elongation dimension includes the length of webbing pulled from the left retractor. The actual elongation of the lap belt assembly, exclusive of webbing pulled from the retractors, was therefore equal to the difference between the right and left elongation dimensions.

The data from the lap belt assembly test, presented in Table 9, show that the assembly failed at 4,024 pounds, with an elongation of 3.54 inches at 4,000 pounds. The assembly failed when the left locking dog of the buckle was pulled through the buckle's side. When the buckle failed, its release mechanism was activated; then the buckle separated from the right side of the lap belt and, after being thrown into the air, ended up in the position shown in Figure 24.

SHOULDER HARNESS ASSEMBLY TEST

The purpose of the shoulder harness assembly test was to demonstrate the integrity of the assembly, to determine its elongation at the design load, and to measure its failure load.

TABLE 9. LAP BELT ASSEMBLY TEST DATA			
Lap Belt Load (lb)	Actual Elongation (in.)	Left Elongation Indicator	Right Elongation Indicator
100 Preload	0	0	0
500	0.45	0.20	0.65
1,000	0.93	0.32	1.25
1,500	1.66	0.52	2.18
2,000	2.18	0.62	2.80
2,500	2.56	0.77	3.33
3,000	2.88	0.93	3.81
3,500	3.20	1.00	4.20
4,000	3.54	1.10	4.64
Failure 4,024 lb			

An inertia reel, one reflected strap, a shoulder harness collar, and a lower shoulder strap were mounted in the Static Test Fixture (DSL602) as shown in Figure 25. With the buckle fitting and shoulder strap attached to the angle fitting (DSL602-11), the shoulder strap and reflected strap lengths were adjusted to that required to fit a 95th percentile occupant. This resulted in an overall length from the inertia reel to buckle fitting of 31 inches. Next, an initial preload of 100 pounds was applied to the assembly by the hydraulic cylinder, and elongation indicators were attached to three points on the assembly. The first indicator was placed on the webbing just outside the inertia reel; the second indicator was attached to the webbing at the adjuster; and the third indicator was located on the shoulder strap fitting. The actual elongation of the shoulder strap assembly was determined by subtracting the adjuster slippage length and the resultant length pulled off the inertia reel spool from the total elongation measured. The resultant length pulled from the inertia reel spool was a component of the total length pulled off the spool as measured by the total elongation indicator. It was calculated by dividing by two the total length pulled from the inertia reel (because of the roller fitting) and then multiplying by the cosine of one-half of the included angle of the reflected strap.

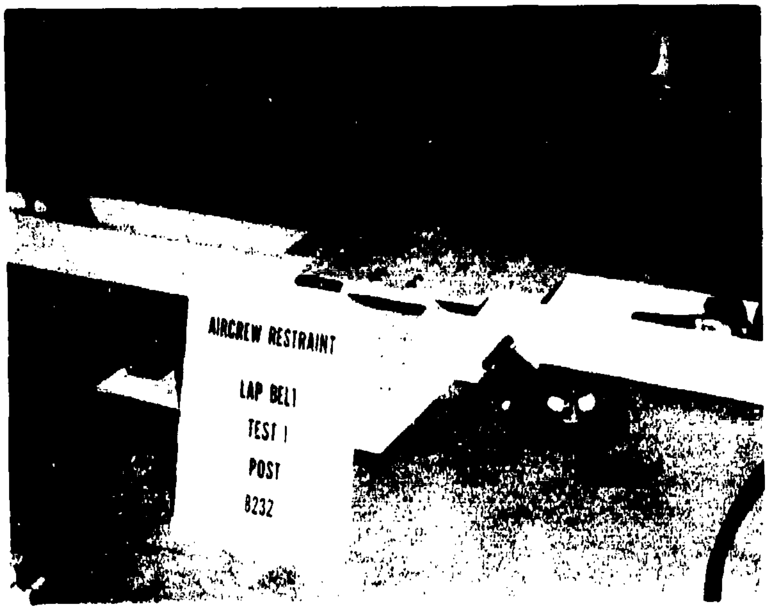


Figure 24. Lap Belt Assembly - Posttest.

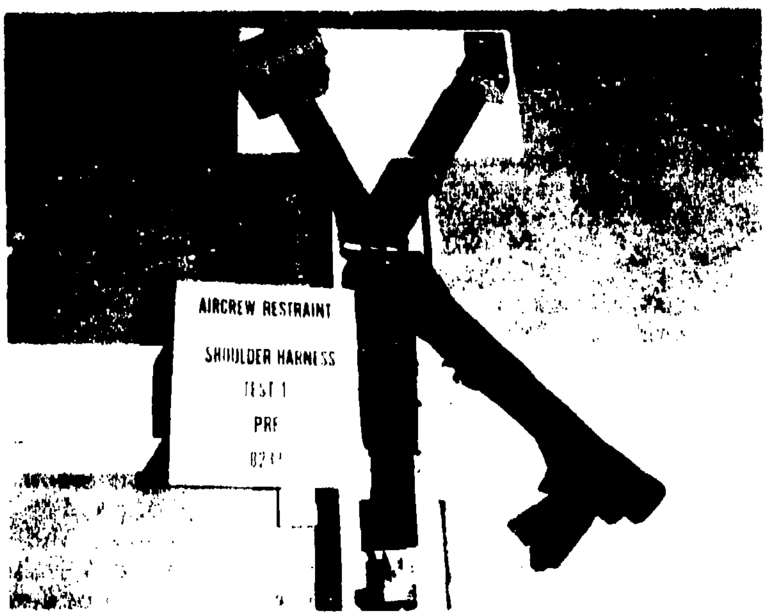


Figure 25. Shoulder Harness Assembly - Pretest.

The data from the shoulder harness assembly test are presented in Table 10, and the posttest results are shown in Figure 26. The elongation of the shoulder harness assembly at the design load of 2,000 pounds was 1.78 inches, and the failure load for this assembly was 2,414 pounds. The failure occurred in the webbing at the point where it is drawn over the knurled bar of the adjuster (see Figure 26). In addition, the locking bar cut into the webbing, but this did not initiate webbing failure. The remaining components of the shoulder harness assembly were undamaged by the test.

TABLE 10. SHOULDER HARNESS TEST DATA

Shoulder Harness (lb)	Actual Elongation (in.)	Total Indicated Elongation (in.)	Adjuster Slippage (in.)	Webbing Off Inertia Reel (in.)	Reflected Strap 1/2 Angle (deg)
100 Preload	0	0	0	0	28.0
500	0.42	0.65	0	0.52	26.5
1,000	0.87	1.34	0.10	0.81	25.0
1,500	1.42	2.15	0.24	1.08	23.5
2,000	1.78	2.70	0.32	1.30	22.5
Failure 2,414 pounds					

TIE-DOWN STRAP TEST

The purpose of the tie-down strap test was to demonstrate its structural integrity, to establish its elongation at the design load, and to determine its ultimate strength.

For this test, a buckle and a tie-down strap were attached to the mounting provisions of the Tensile Test Fixture (DSL605) and placed in the universal testing machine as shown in Figure 27. The single-point release buckle was attached through the upper fitting (DSL605-3) to the load cell on the fixed end of the testing machine, and the tie-down strap anchor was attached to the inclined surface on the lower fixture (DSL605-1), which was bolted to the movable platen of the testing machine. The assembly was preloaded to 100 pounds, and elongation indicators were attached to the buckle and anchor fitting. The loading was continued with the separation rate set at 0.75 inch per minute, and the elongation measurements were recorded at each 500-pound increment.

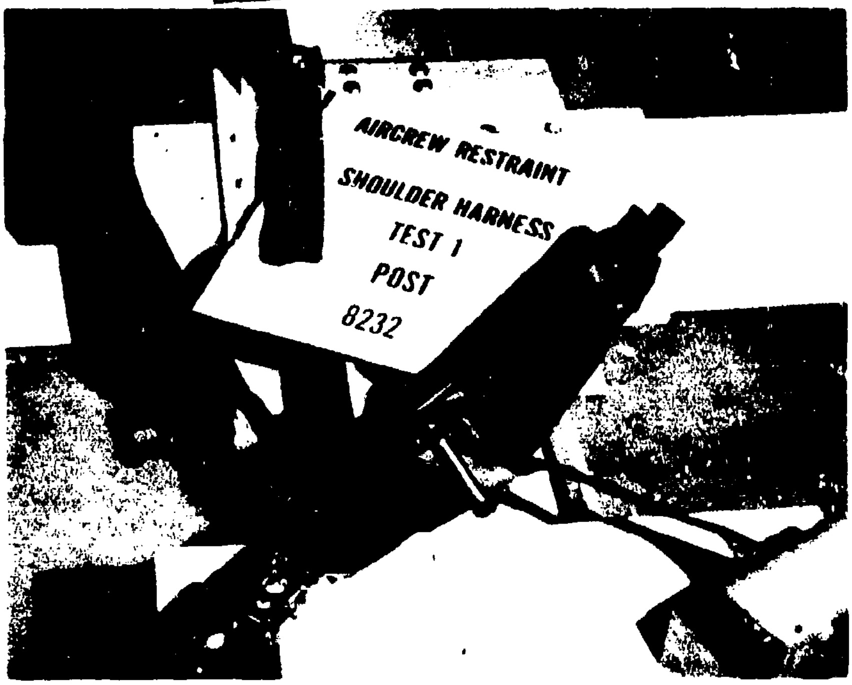


Figure 26. Shoulder Harness Assembly - Posttest.

Data from the initial tie-down strap test, presented in Table 11, indicate that a premature failure occurred at approximately 1,800 pounds, when the tie-down fitting separated from the buckle. The failure was the result of the tie-down fitting's pulling loose from the buckle; however, there did not appear to be any major damage to either part. The cause of this failure was determined to be a small radius on the contact surface of the fitting, which permitted it to ride up the face of the latching dog, and release itself from the buckle.

The buckle assembly was subsequently returned to Pacific Scientific Company for rework. The design change to correct this discrepancy was to rigidly attach the tie-down fitting to the load plate of the buckle by a special rivet. This fix was implemented by PSCo and the unit was retested. The results of this test are shown in Table 12. The assembly failed at 2,968 pounds when the webbing in the tie-down fitting separated. The elongation at 2,500 pounds was 0.81 inch.

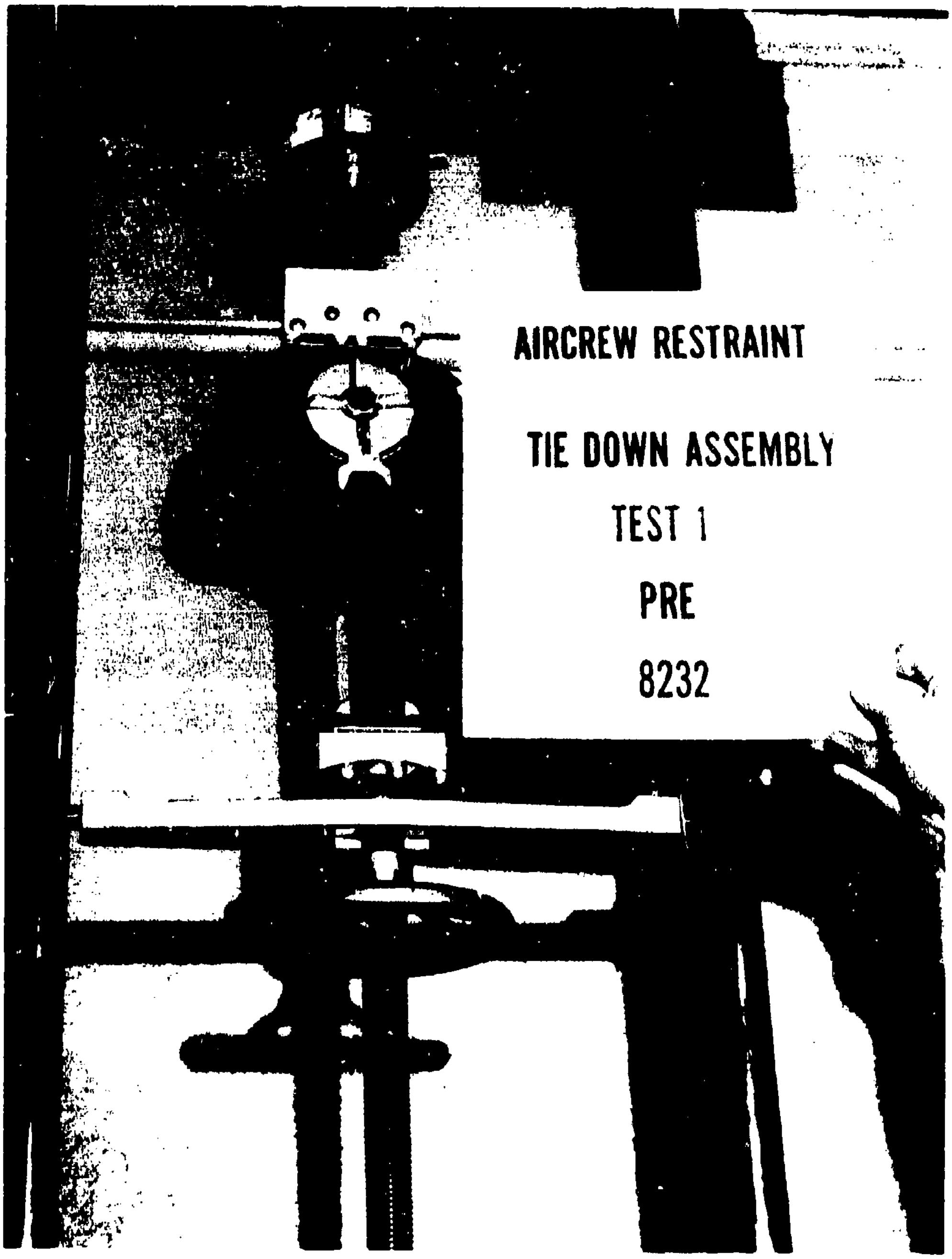


Figure 27. Tie-Down Strap Test Configuration.

TABLE 11. TIE-DOWN ASSEMBLY TEST (INITIAL)	
Lap Belt Load (lb)	Total Elongation (in.)
100 Preload	0
500	0.20
1,000	0.40
1,500	0.55
Failure 1,800 lb (approx.)	

TABLE 12. TIE-DOWN ASSEMBLY TEST (RETEST)	
Lap Belt Load (lb)	Total Elongation (in.)
100 Preload	0
500	0.18
1,000	0.38
1,500	0.55
2,000	0.68
2,500	0.81
2,968 - Failure	1.05

HARDWARE COMPONENT TESTS

The purpose of the hardware component tests was to establish the ultimate load and failure mechanism of each piece of metallic hardware in the restraint system. These tests were conducted by Pacific Scientific Company at their testing laboratory in Anaheim, California. Each hardware element of the restraint system was mounted in PSCo's tensile machine and loaded to failure. The results of these tests are summarized in Table 13 and discussed on the following page.

TABLE 13. HARDWARE TEST RESULTS

Hardware Component	Failure Load (lb)	Failure Mechanism
Single-Point Release Buckle		
Lap Belt Attachment	4,220	Locking dog and load plate failure
Shoulder Strap Attachment	4,220*	Locking dog and load plate failure
Tie-down Strap Attachment	2,935	Webbing failure
Tie-down Strap Anchor	6,200**	Mounting bolt failure
Lap Belt Retractor	5,030	Webbing failure
Adjuster	2,720	Webbing failure
Reflected Strap Anchor	4,240	Webbing failure
Roller Fitting	7,320**	Webbing failure

*Based on similarity to the lap belt attachment.
**High-strength webbing (7,000 pounds) used for test.

Single-Point Release Buckle

The single-point release buckle was tested in two configurations: one, shown in Figure 28, was a straight pull to test the lap belt attachment; and the other, shown in Figure 29, was used to test the tie-down strap connection. The ultimate load for the lap belt attachment was 4,220 pounds. Two types of failures were observed. In one instance (see Figure 30), a restraining tab on the locking dog failed; in the other (see Figure 31), the locking dog and load plate failed simultaneously. The ultimate load was 2,935 pounds for the tie-down connection, which produced a webbing failure at the fitting. The ultimate strength and failure mechanism for each shoulder strap attachment were determined to be the same as the lap belt attachment because they have the same configuration.

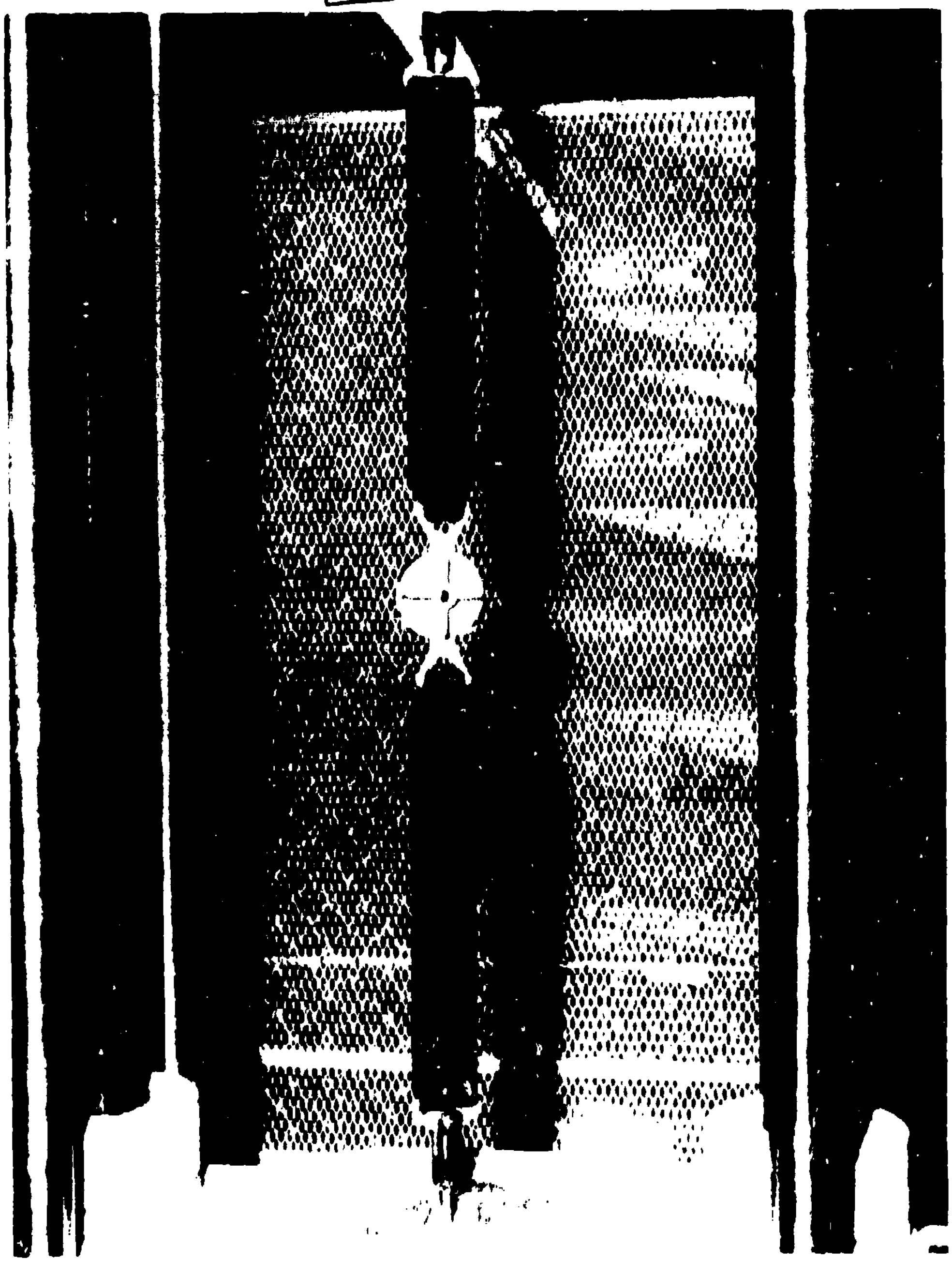


Figure 28. PSCo's Buckle Test Configuration - Lap Belt Connection.

Figure 29. PSCo's Buckle Test Configuration - Tie-Down Connection.

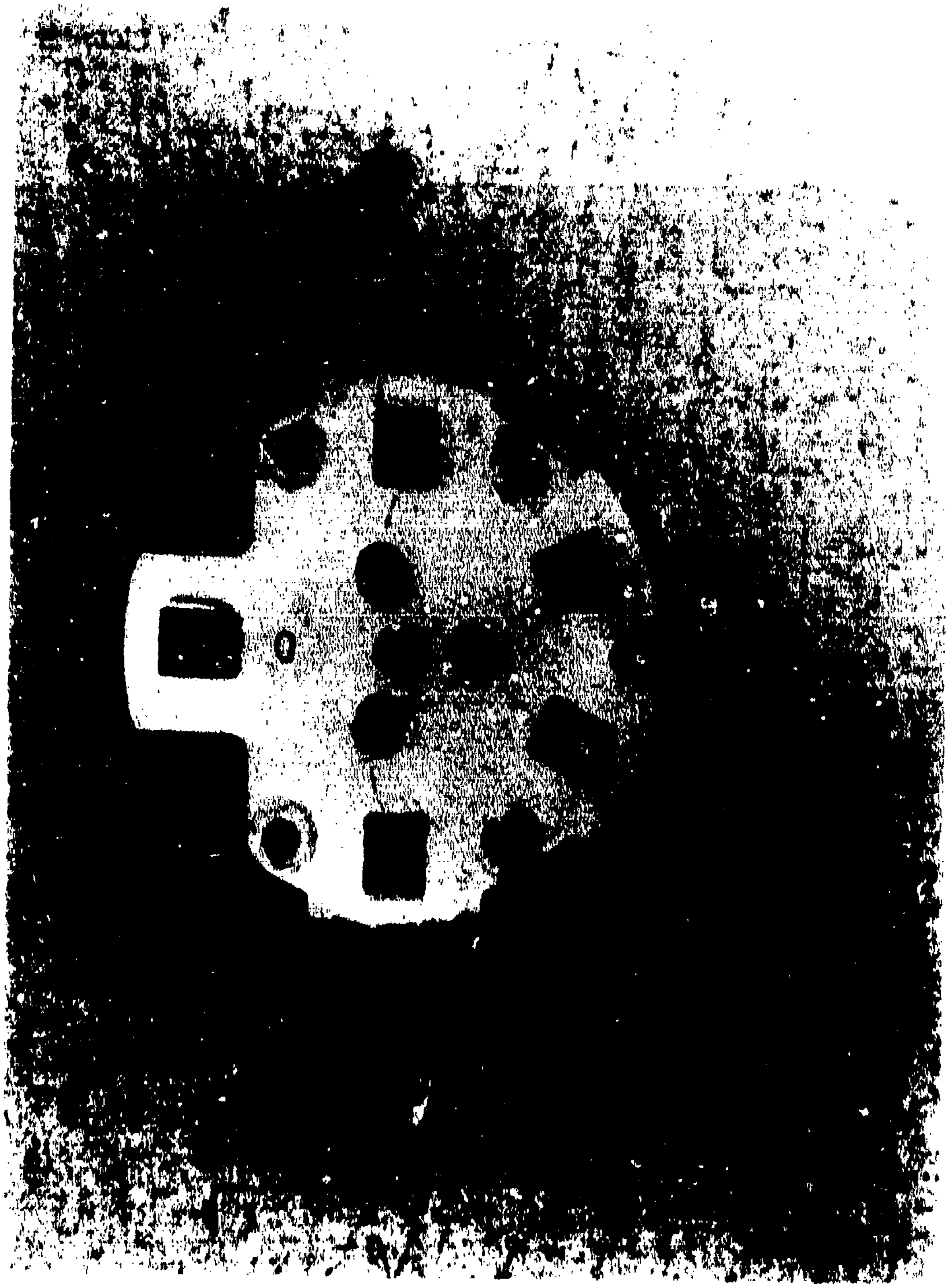


Figure 30. Buckle Locking Dog Failure.

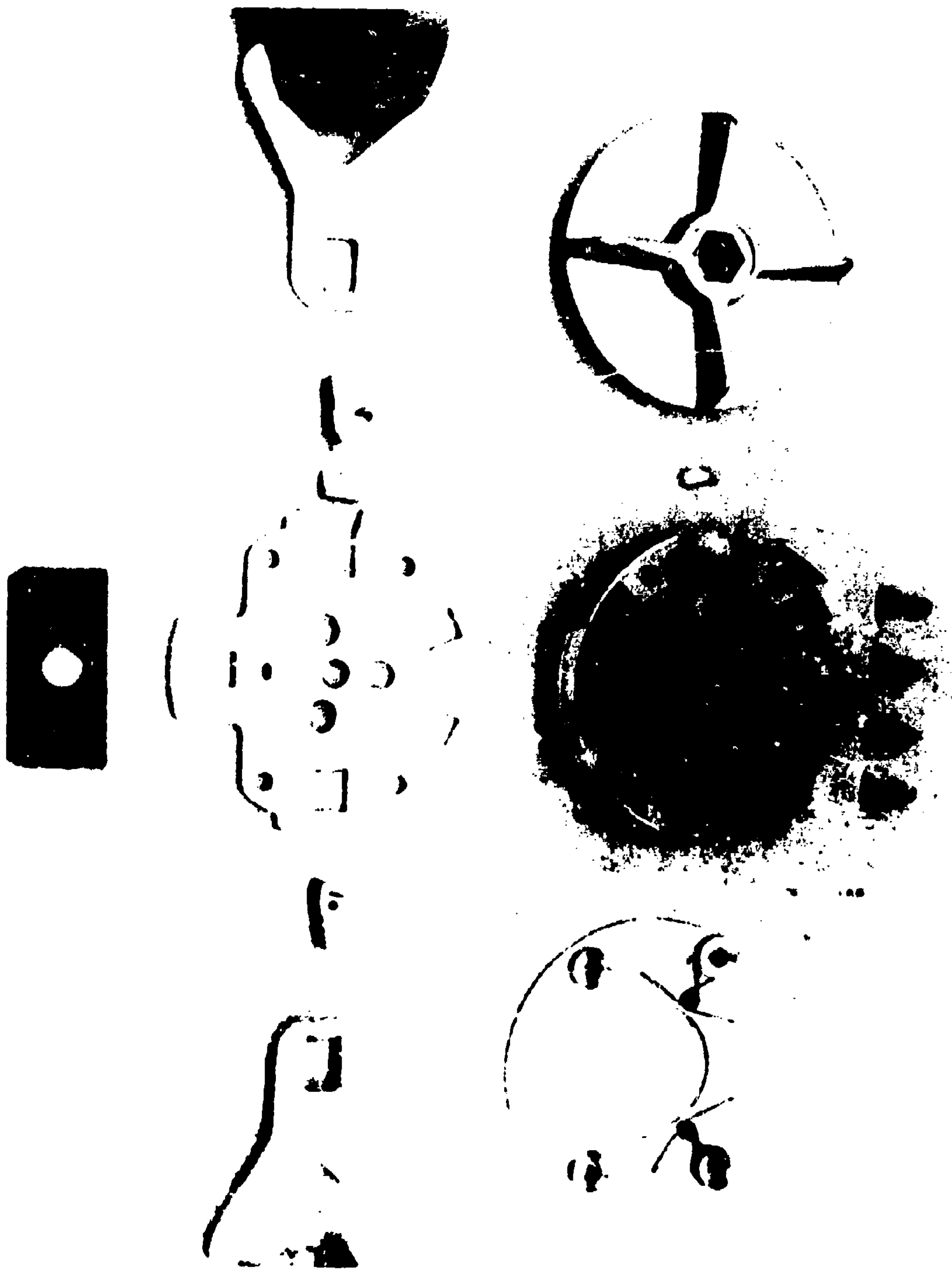


Figure 31. Buckle Load Plate and Locking Dog Failure.

Tie-Down Strap Anchor

The tie-down strap anchor was subjected to a load of 6,200 pounds as shown in Figure 32, using high-strength webbing (MIL-W-25361, Type III). The test was terminated at this load due to failure of the mounting bolts. No further testing was performed because 6,200 pounds exceeds the design load of 2,500 pounds by a factor of 2.5.

Lap Belt Retractor

The ultimate load for the lap belt retractor was 5,030 pounds, and at this load the webbing failed at the buckle fitting. The test configuration for this unit is shown in Figure 33. The initial test of the retractor produced a failure at 4,000 pounds when the locking bar sheared a tooth off of the spool's rachet wheel. The locking bar was then modified by adding a 15-degree bevel to the top of the bar. This change permitted a more complete engagement of the locking bar with the rachet wheel tooth and increased the retractor's ultimate load.

Adjuster

The adjuster was tested, as shown in Figure 34, with two different webbings: MIL-W-25361, Type III, and 1.75-inch-wide low-elongation polyester webbing manufactured by Murdock Webbing Company. With the MIL-W-25361 webbing, the adjuster failed at 3,240 pounds when the webbing was cut by the knurled lock bar. The same type of failure occurred at 2,720 pounds when the Murdock webbing was used in the adjuster.

Reflected Strap Anchor

An inertia reel with a reflected strap and anchor was tested to 4,240 pounds when the webbing failed at the anchor fitting. The anchor was then tested separately, as shown in Figure 35; it failed at 6,200 pounds. The fitting separated at the webbing loop when the material failed at this point.

Roller Fitting

The roller fitting was tested, as shown in Figure 36, with high-strength webbing (MIL-W-25361, Type III). At 7,320 pounds, the webbing failed at the tester fitting, and the test was discontinued. The roller fitting was examined, and the only damage observed was a slight deformation in the roller frame. The deformation prevented the roller from rotating freely; however, it satisfactorily passed the test.

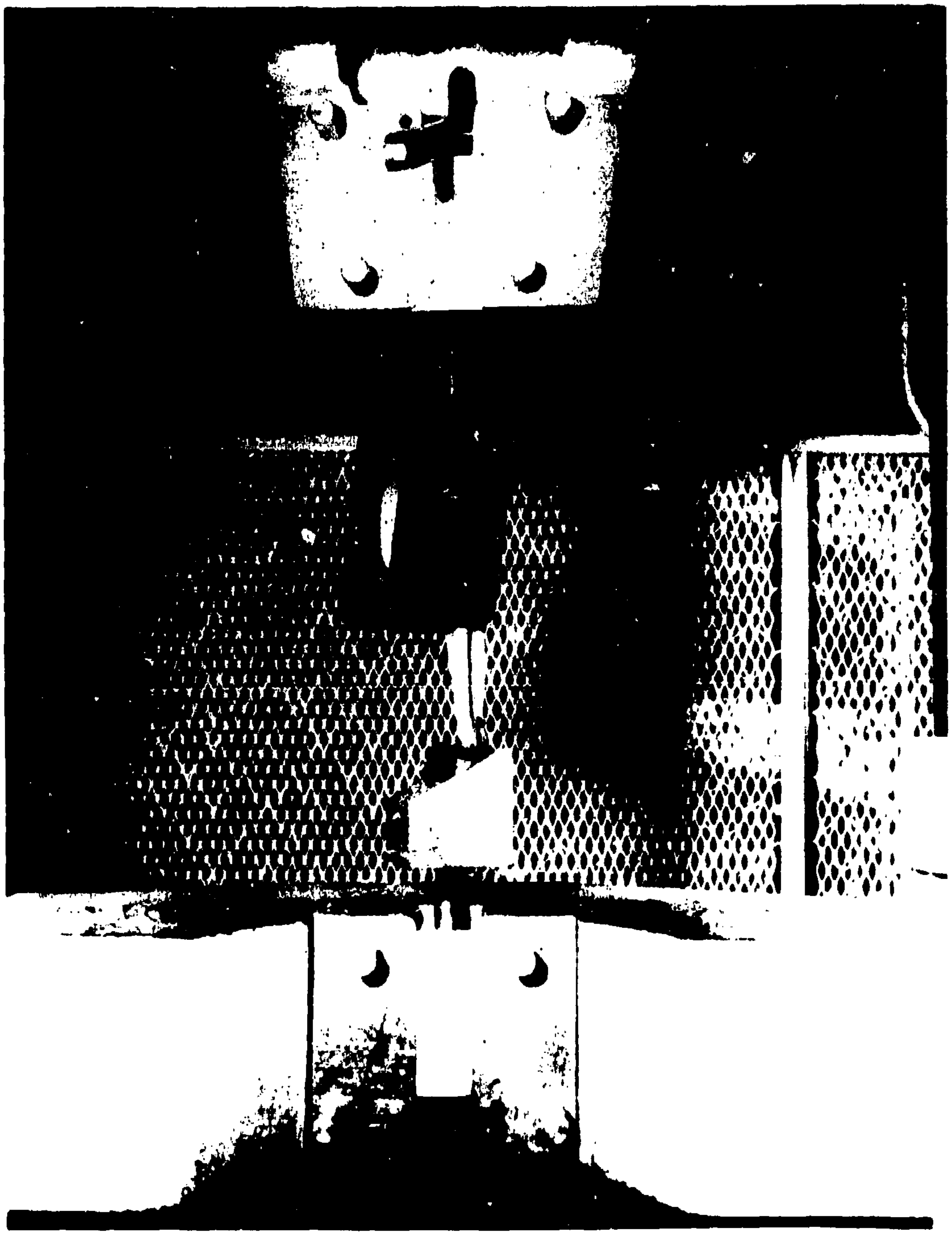


Figure 32. PSCo's Tie-Down Anchor Test Configuration.

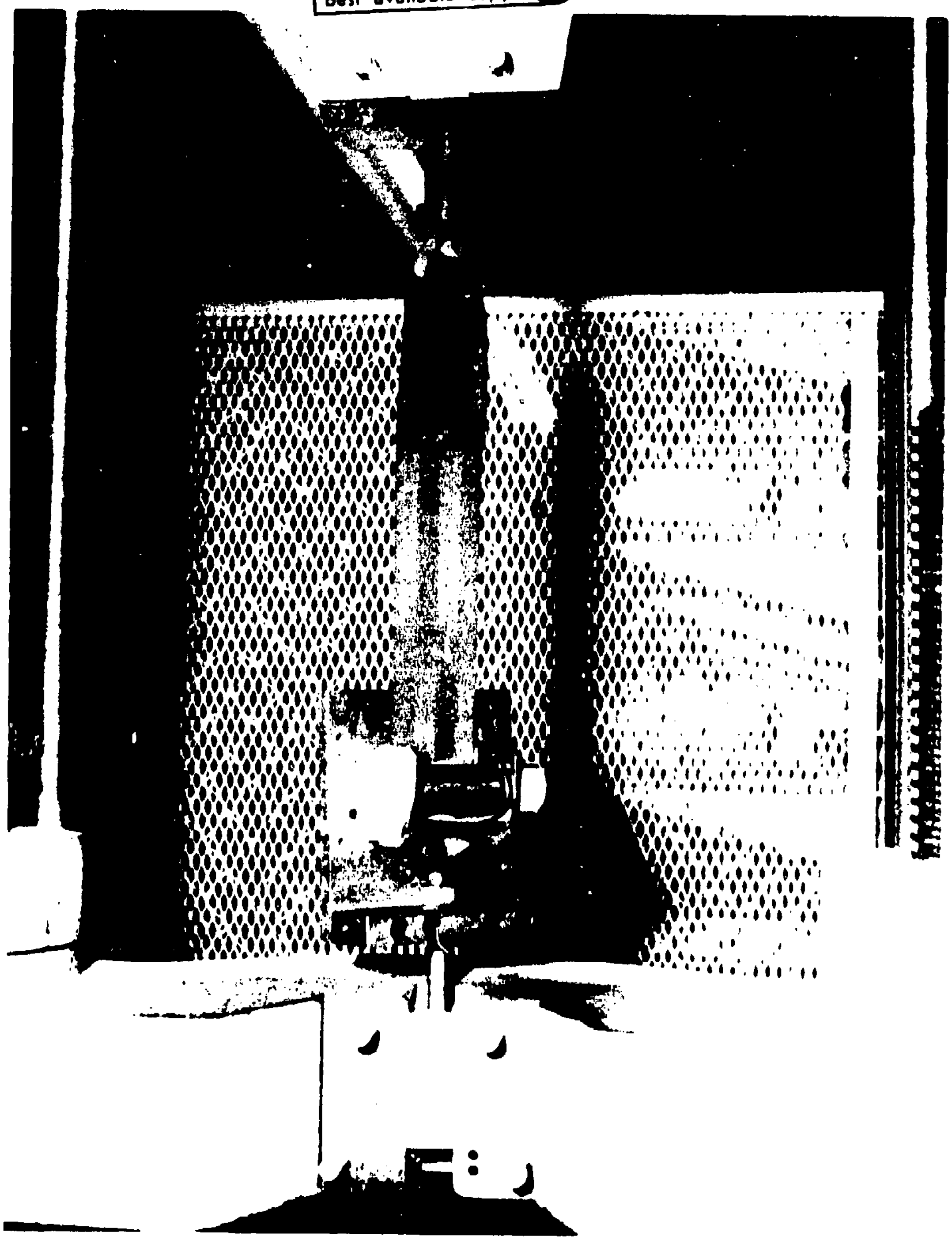


Figure 33. PSCo's Retractor Test Configuration.

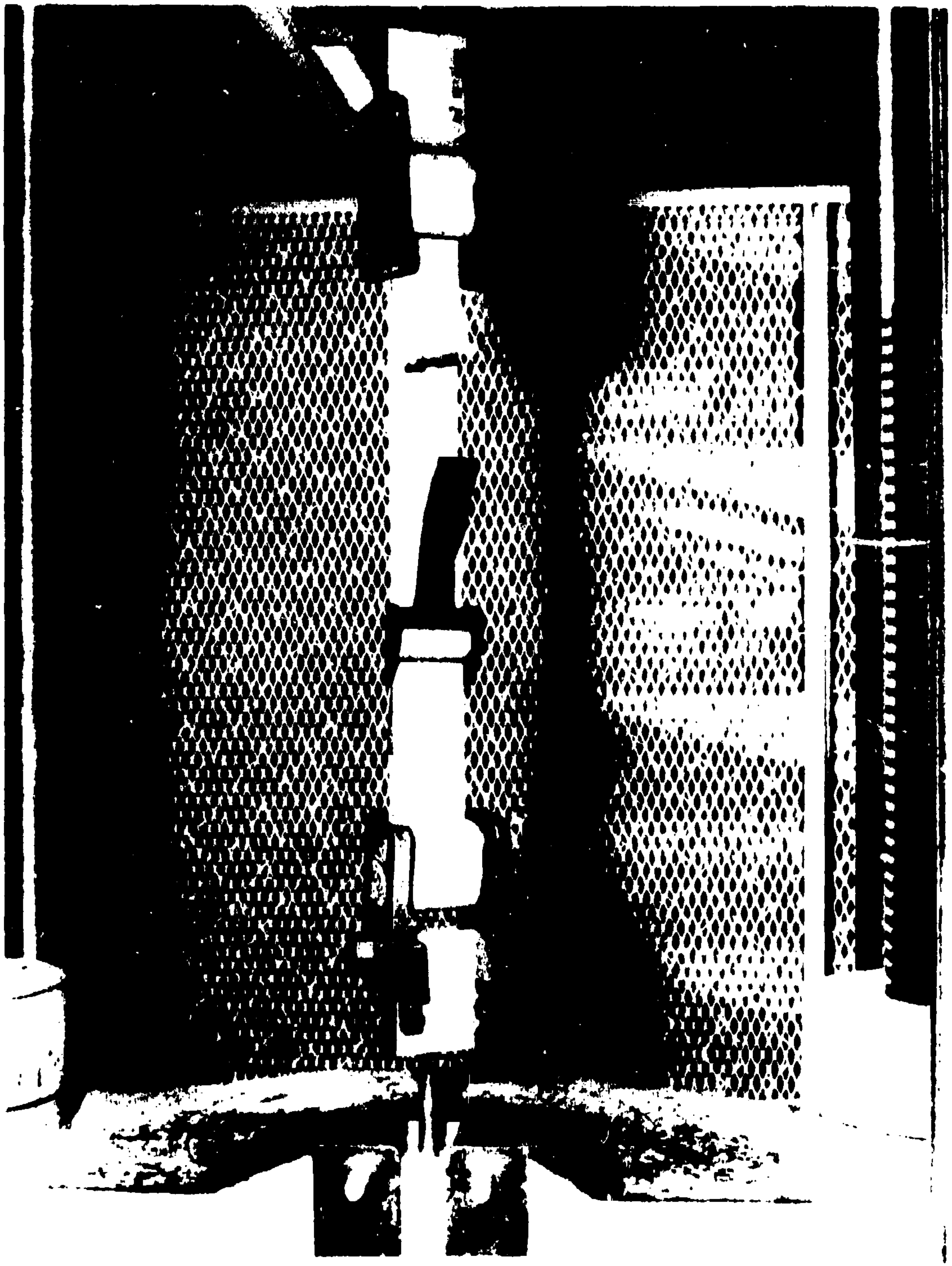


Figure 34. PSCo's Adjuster Test Configuration.

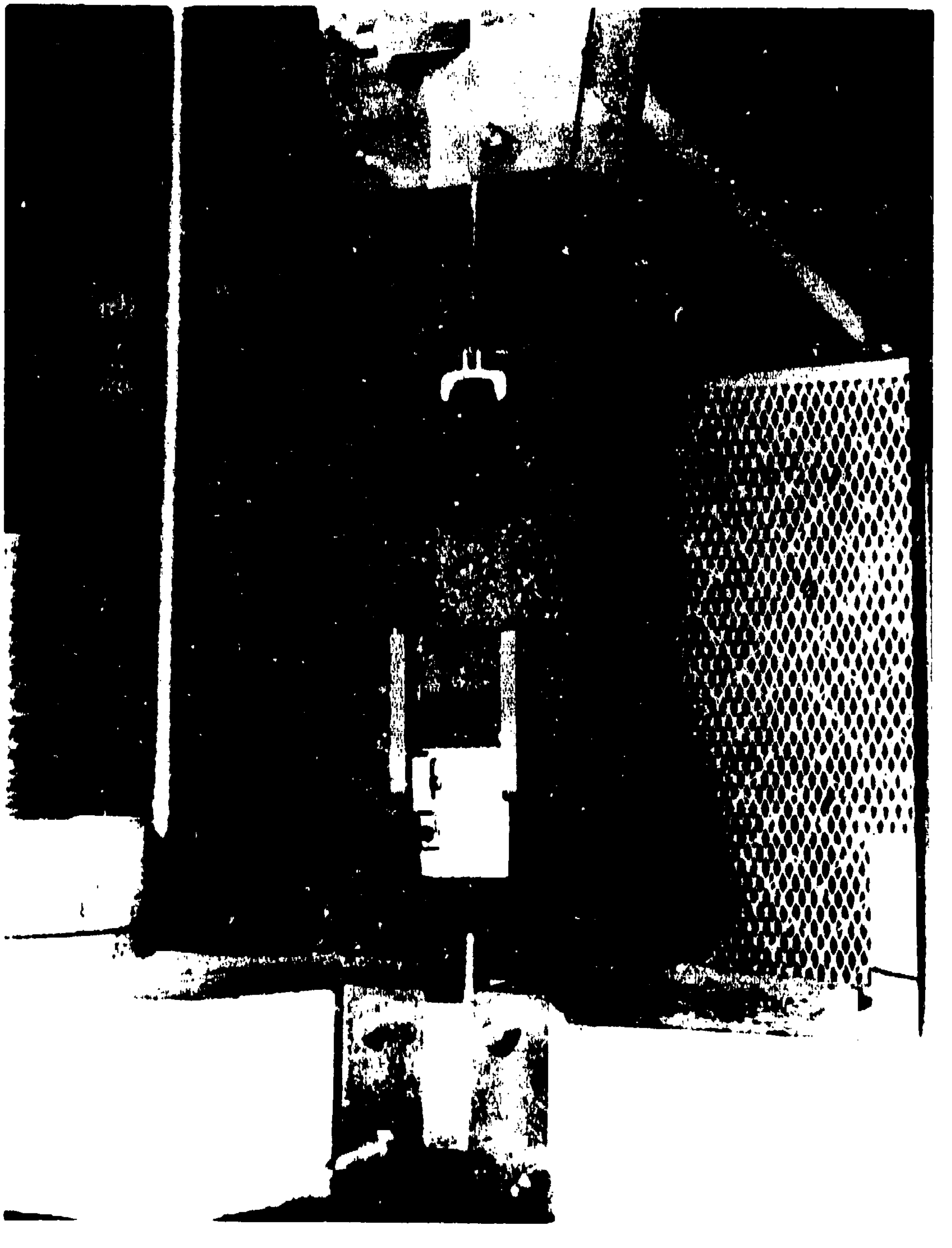


Figure 35. PSCo's Reflected Strap Anchor Test Configuration.

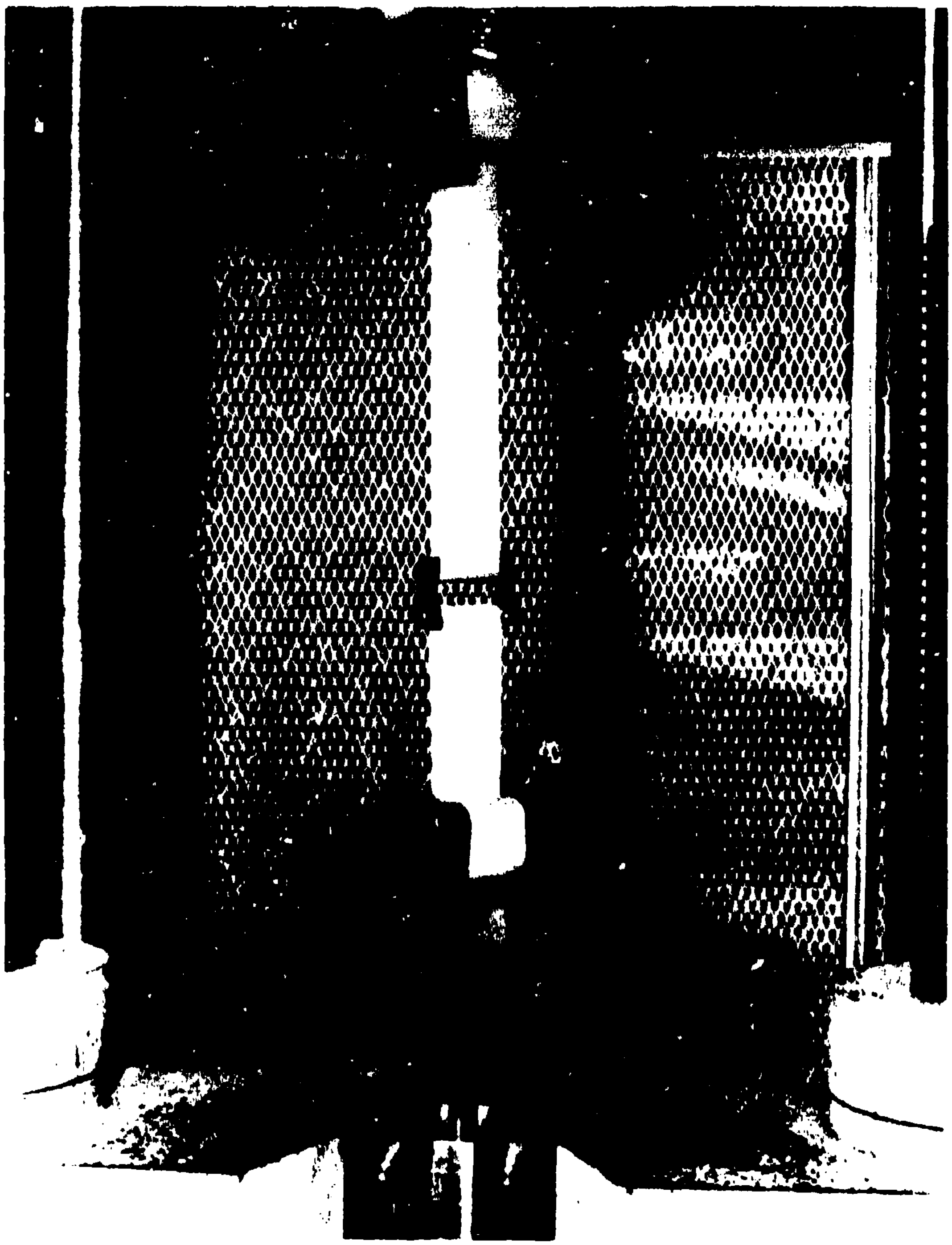


Figure 36. PSCo's Roller Fitting Test Configuration.

RETRACTOR TESTS

The lap belt retractors were subjected to a locking test and an extension load test. The retractor locking test was conducted to demonstrate the reliability of the retractor's locking mechanism and to provide an indication of its resistance to wear. The purpose of the extension load test was to establish that the force required to extend the webbing from the retractor was within the required limits of not less than 7-1/2 pounds or more than 15 pounds when the webbing was withdrawn at a typical operational rate.

For the locking test, the retractor was mounted on the Functional Test Fixture (DSL603), with the retractor housing attached to the slide plate (DSL603-7) and the buckle fitting attached to the traveler base (DSL603-17), as shown in Figures 37 and 38. The test fixture was then energized, applying an extension load to the webbing and pulling it out of the retractor at an average rate of 20 ±2 inches per second. After 12 inches of webbing had been extended, the motion was stopped by the test mechanism for 0.6 second to allow the retractor to lock. The extension load was then reapplied to the retractor, and, since it had locked, there was no further relative motion between the buckle fitting and the retractor housing. The retractor spring (DSL603-5) permitted the retractor housing to move forward so that the crank mechanism would continue to rotate and allow the webbing to rewind on the retractor. When the test fixture had reached its initial position, it was stopped again for 0.6 second to ensure that the retractor would be stabilized for the next locking cycle. This sequence was repeated automatically in 50-cycle increments until 1,000 tests had been performed. The test fixture was stopped after each 50 cycle period to ensure that heat generated within the retractor would not be a factor in the test results. For this test, two mechanical counters were used to monitor retractor locking. One counted the traveler base revolutions, and the other counted the slide plate strokes. If the retractor failed to lock during the cycle, the slide plate counter would indicate less than the traveler base counter, with the difference being the number of times the retractor failed to lock.

The only difficulty encountered during the retractor locking tests was that the relationship of the stopping cam to the crank mechanism changed slightly with each cycle. This change could be adjusted to some degree; but as the brake's temperature increased, additional adjustment was required. Therefore, an initial adjustment that would last for 50 cycles was made, and the crank mechanism was repositioned during the waiting period between each 50-cycle series of tests.

Figure 37. Retractor Mounting for Locking Test.

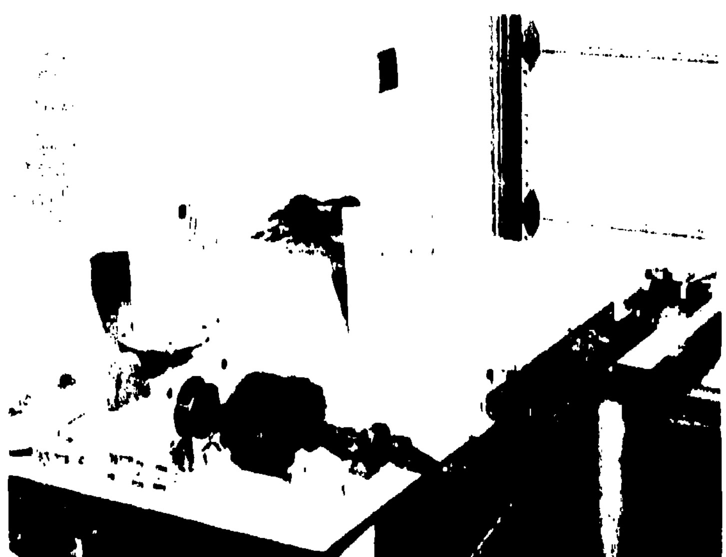


Figure 38. Retractor Locking Test Configuration.

The retractor locking test was completed with no observed evidence of damage or wear to the retractor. It was still functioning normally after 1,000 locking cycles. At the completion of the test, the number of counts on both counters were the same, indicating that the retractor had successfully locked on every cycle.

The Functional Test Fixture (DSL603) was also used to measure the retractor's extension load. The retractor housing was mounted to the slide plate (DSL603-7), and the buckle fitting was mounted to the traveler base (DSL603-17). The extension load was measured by a load cell that replaced the retractor spring (DSL603-5) used in the previous test. The load cell was fastened between the slider plate and the mounting table as shown in Figures 39 and 40. After mounting the retractor in the test fixture, the motor was energized and allowed to reach operating speed with the clutch disengaged and the brake set. The brake was then released, the clutch was engaged, and the webbing was withdrawn from the retractor at an average speed of 20 ±2 inches per second. When the webbing had reached its fully extended length, the motion of the traveler base was reversed and the retractor's tension force returned the webbing to its initial position. This sequence was repeated five times. During each cycle of the test, the output from the load cell was continuously monitored on a strip-chart recorder. The results of the five tests are shown in Table 14.

The retractor performed normally throughout the test series, and there was no indication of damage in the posttest examination. However, the retractor loads reached an average maximum value of only 7 pounds, which is less than the minimum established by the proposed specification. This discrepancy was discussed with Pacific Scientific Company, and it was agreed that the spring load in the retractor should be increased so that the requirements of the specification could be met. The retractor was shipped back to PSCo for rework and returned to Dynamic Science for additional testing. The reworked retractor was subsequently retested, and a minimum extension load of 8 pounds was measured at the unlocked length, while a maximum load of 14.75 pounds was measured at the fully extended length. Since both of these loads are in compliance with the proposed specification, the reworked retractor successfully passed the extension load test, and the new spring was incorporated into the retractor's design.

ADJUSTER TESTS

The adjuster was subjected to a webbing abrasion test and an adjustment load test. The purpose of the webbing abrasion test was to demonstrate that the adjuster would allow the

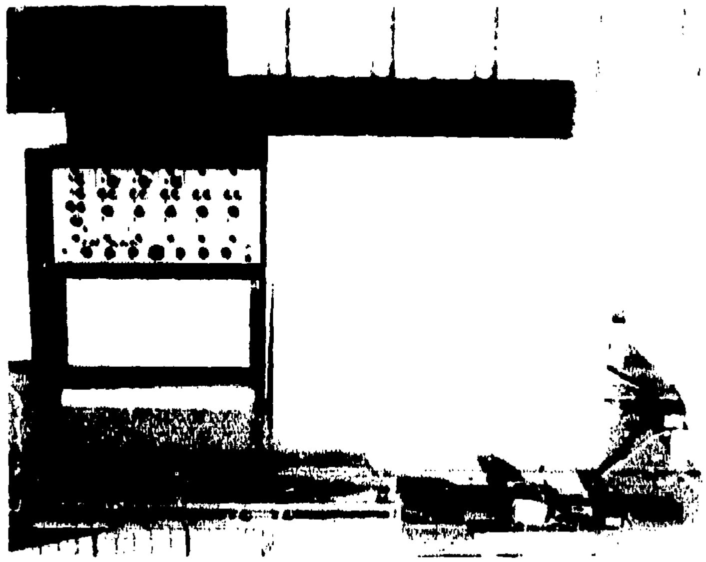


Figure 39. Retractor Extension Load Test Configuration.

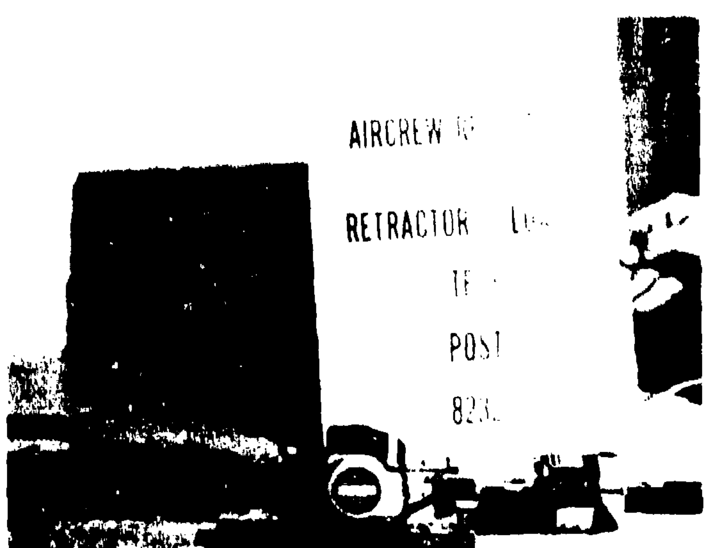


Figure 40. Retractor Mounting for Extension Load Test.

TABLE 14. RETRACTOR LOAD TEST DATA	
Test Number	Maximum Retractor Resistance Load (lb)
1	7.00
2	7.00
3	6.75
4	7.50
5	7.25

webbing to be drawn through it, without undue wear or damage to the webbing or the adjuster. The purpose for the adjuster load test was to demonstrate that the force required to make a webbing adjustment did not exceed 15 pounds.

The webbing abrasion test was conducted by mounting the adjuster to a special plate installed on the Functional Test Fixture (DSL603) that oriented the adjuster in the same position that it occupies in the shoulder harness collar assembly. The adjuster mount (DSL603-55), with the adjuster attached, was bolted in place on the guide channel (DSL603-11), and the adjuster's locking mechanism was positioned in the release mode. Next, the free end of the webbing was threaded through the adjuster and attached to the traveler base (DSL603-17). The shoulder strap was then pulled down through the clearance slot in the guide channel. With the webbing's free end placed 4 inches away from the adjuster, a 5-pound weight was attached. This was the minimum weight which would pull the webbing back through the adjuster at a rate that eliminated backlash. The configuration for the webbing abrasion test is illustrated in Figure 41.

To conduct the test, the motor was energized; and after operating speed had been achieved, the clutch was engaged. This caused the webbing to be pulled back and forth through the adjuster at an average rate of 20 ±2 inches per second. This operation was repeated 1,000 times in 10-cycle increments to avoid excessive heating of the webbing due to friction. A small temperature increase was noticeable after the webbing had been cycled through the adjuster ten times. To prevent this effect from influencing the test results, the adjuster and webbing were permitted to reach room temperature before the next series of ten tests was made.

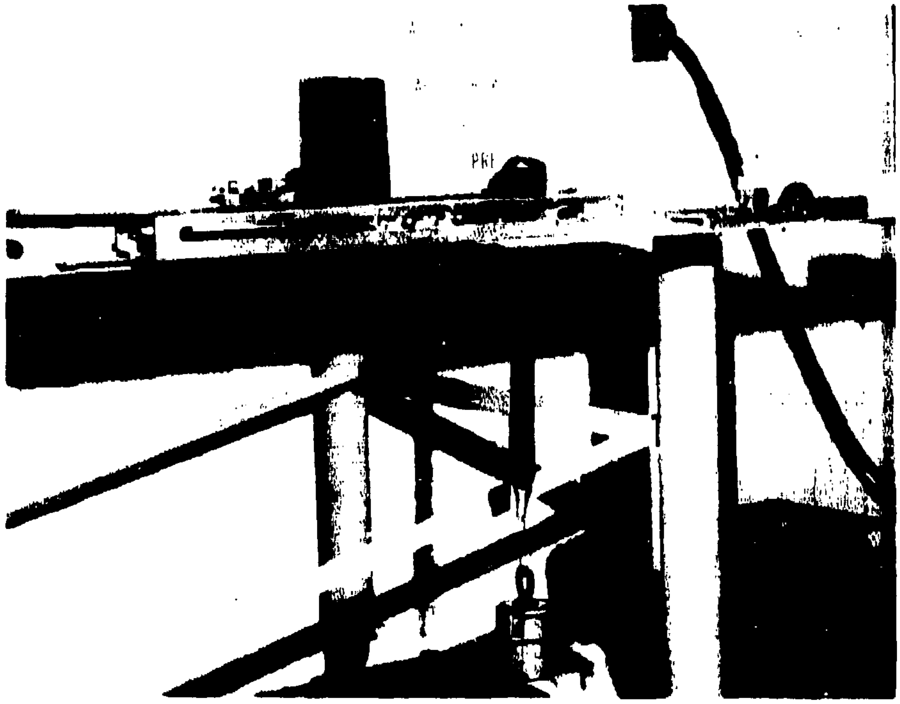


Figure 41. Adjuster Webbing Abrasion Test Configuration.

Webbing wear was observed after 100 simulated adjustments. Fraying of the webbing occurred where it contacted the large knurled bar of the adjuster. The fraying consisted of small fibers that would increase in length as the webbing was cycled, then break off and regenerate. This produced concentrated areas of wear that extended along the length of webbing. During the return stroke of the adjustment cycle, the webbing favored one side of the adjuster, and the radius of the knurled bar caused a small deformation of the webbing that produced a noticeable curl in the webbing when it was removed from the adjuster. The test sample is shown in Figure 42. After the abrasion test was completed, the webbing strap was subjected to a 3,500-pound load. At this load, the webbing slipped from the test jaws and the test was terminated; however, the results did indicate that the deterioration of the webbing, due to abrasion, was not sufficient to decrease the webbing's load below the design load of the shoulder strap (2,000 pounds).

The adjuster load test was performed using the Functional Test Fixture (DSL603-7), with the adjuster mounted to the slide

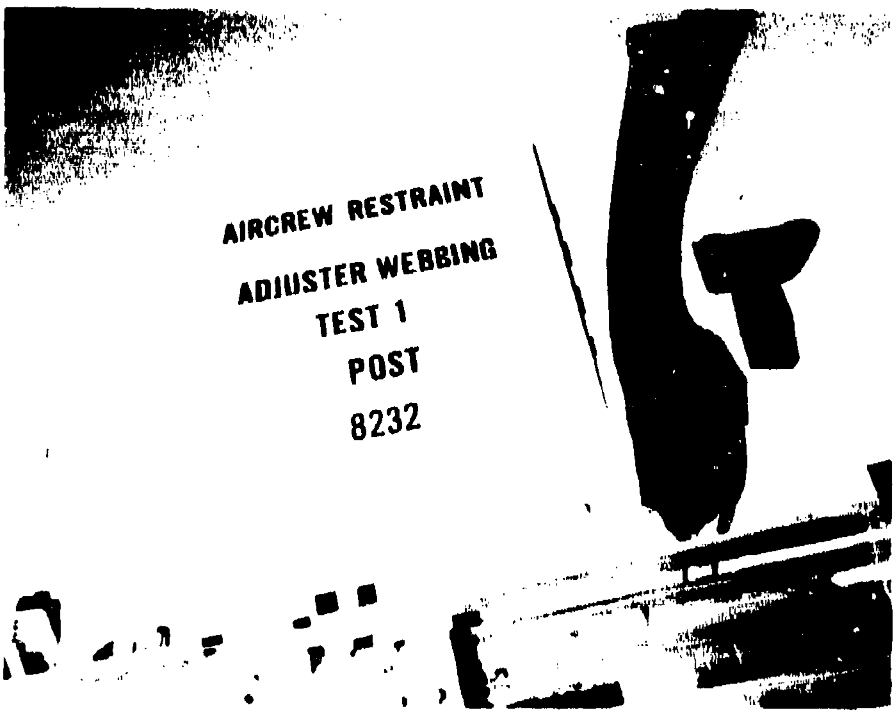


Figure 42. Adjuster Webbing Abrasion Test Results.

plate (DSL603-7) and the free end of the webbing attached to the traveler base (DSL603-17), as shown in Figures 43 and 44. The distance between the adjuster frame and the webbing's free end was 2 inches. The motor was then energized, and after it had reached operating speed, the clutch was engaged and the webbing was pulled through the adjuster at an average rate of 20 ±2 inches per second. When the traveler base had reached a displacement of 10 inches, the clutch automatically disengaged, and the webbing was manually returned to its initial position. This sequence was repeated five times, and the force required to pull the webbing through the adjuster was continuously recorded during each test.

The data from the adjuster load test, presented in Table 15, indicate that the adjustment load is well below the 15-pound maximum limit. In addition, neither the adjuster nor the webbing showed any wear or damage as a result of these tests.

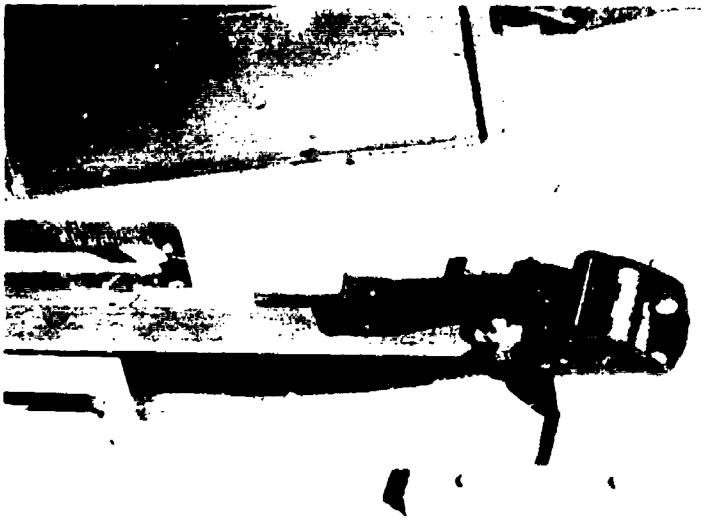


Figure 43. Adjuster Mounting for Load Test.

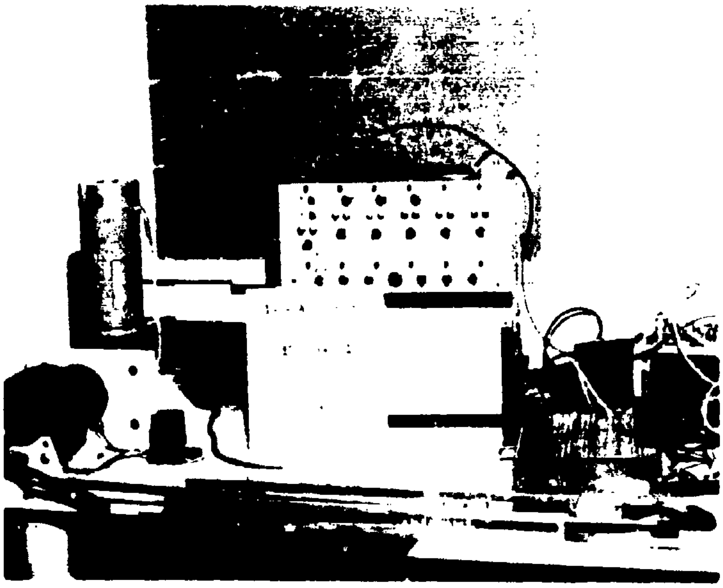


Figure 44. Adjuster Load Test Configuration.

TABLE 15. ADJUSTER LOAD TEST DATA		
Test Number	Adjuster Resistance Load (lb)	
	Starting Load	Constant Load
1	7.5	2.25
2	7.0	1.75
3	5.0	1.50
4	7.0	1.25
5	6.0	1.50

ROLLER FITTING TEST

The purpose of the roller fitting tests was to demonstrate that the roller fitting would allow the webbing to pass through it without undue wear or damage to either the roller or the webbing during accelerated usage.

The roller fitting test was conducted on the Functional Test Fixture (DSL603), with the inertia reel and fixed end mounts (DSL602-25 and DSL602-31) installed as mounting surfaces for the inertia reel and reflected strap end fitting. The roller fitting was attached to the extension link (DSL603-13) of the Functional Test Fixture, with the reflected strap webbing passing through it as shown in Figure 45. The test was initiated by energizing the motor, allowing it to reach operating speed, and then engaging the clutch. This caused the roller fitting to move away from the inertia reel at an average rate of 20 ±2 inches per second. After the roller fitting traveled a distance of 12 inches, the extension link reversed its motion and returned the roller fitting to its initial position, while the inertia reel retraction force wound up the webbing on the spool. After the roller fitting had reached the initial position, this cycle was repeated. This test was performed 1,000 times, in 50-cycle increments to avoid frictional heating. The roller fitting and webbing were then removed for inspection.

During the test, neither noticeable wear of either the webbing or the roller fitting nor an increase in temperature was observed. However, the reflected strap did have a tendency to rub against one side of the roller fitting because of the takeoff angle. This did not seem to produce any noticeable wear on either the webbing or the roller fitting. The roller fitting

Figure 45. Roller Fitting Test Configuration.

test was completed with no visible wear or damage to either the roller fitting or the webbing.

INERTIA REEL TEST

The inertia reel was to be tested by Pacific Scientific Company in accordance with the quality assurance provisions of MIL-R-8236, Type MA6. However, these tests had been previously conducted by PSCo in order to qualify their inertia reel as a Type MA6, and the documentation of their unit as a qualified inertia reel was presented to USAAMRDL to satisfy this requirement.

ACCELERATION RESISTANCE TESTS

Both the adjuster and the retractor locking mechanism were to have been subjected to a triangular acceleration pulse with a 35G peak and a time duration of 100 msec in the critical

direction with no preload on the webbing and with no unlocking motion of the mechanism occurring during the test. However, this test could be waived if an analysis showing that no unlocking could be caused by the test load was performed. For this program, an analysis was performed for both units, and the results, demonstrating that neither unit will unlock, are presented in Appendix B and Appendix C.

BUCKLE RELEASE TEST

The buckle release test was performed on a single-point release buckle using the Static Test Fixture (DSL602) and the Torque Fixture (DSL604) as shown in Figure 46. The purpose of this test was to demonstrate the performance and repeatability of the buckle's quick-release mechanism. The test requirements were also established to demonstrate the fitting release performance of the buckle after it had been subjected to the design loads of the webbing and with residual loads in the webbing members roughly typical of those which might exist in an overturned aircraft, with the weight of the occupant supported entirely by the restraint system. The Static Test Fixture was used to apply the simulated residual loads to each of the buckle fittings, while the Torque Fixture provided the means for rotating the buckle handle, as well as measuring the torque applied to the handle and its angular rotation. The results of this test were used to establish the rotation angle required to release all the straps from a starting position in either direction, and to determine the release angle or angles for each buckle fitting. The test results were also used to establish the variation in release position between clockwise and counterclockwise rotation.

The release test was initiated by mounting an untested buckle on the Torque Fixture's base plate (DSL604-23), a heavy steel plate whose purpose was to keep the buckle more or less stationary during rotation of the buckle handle and release of the fittings. Then the following preloads were applied to the buckle fittings:

- Lap belt load - 100 pounds
- Shoulder strap load - 50 pounds
- Tie-down strap load - 100 pounds

The preload was first applied to the tie-down strap and used to align the Torque Fixture so that a straight pull could be made when the lap belt was loaded. The lap belt preload was applied through two hydraulic cylinders which were used to keep the Torque Fixture located in the center of the Static

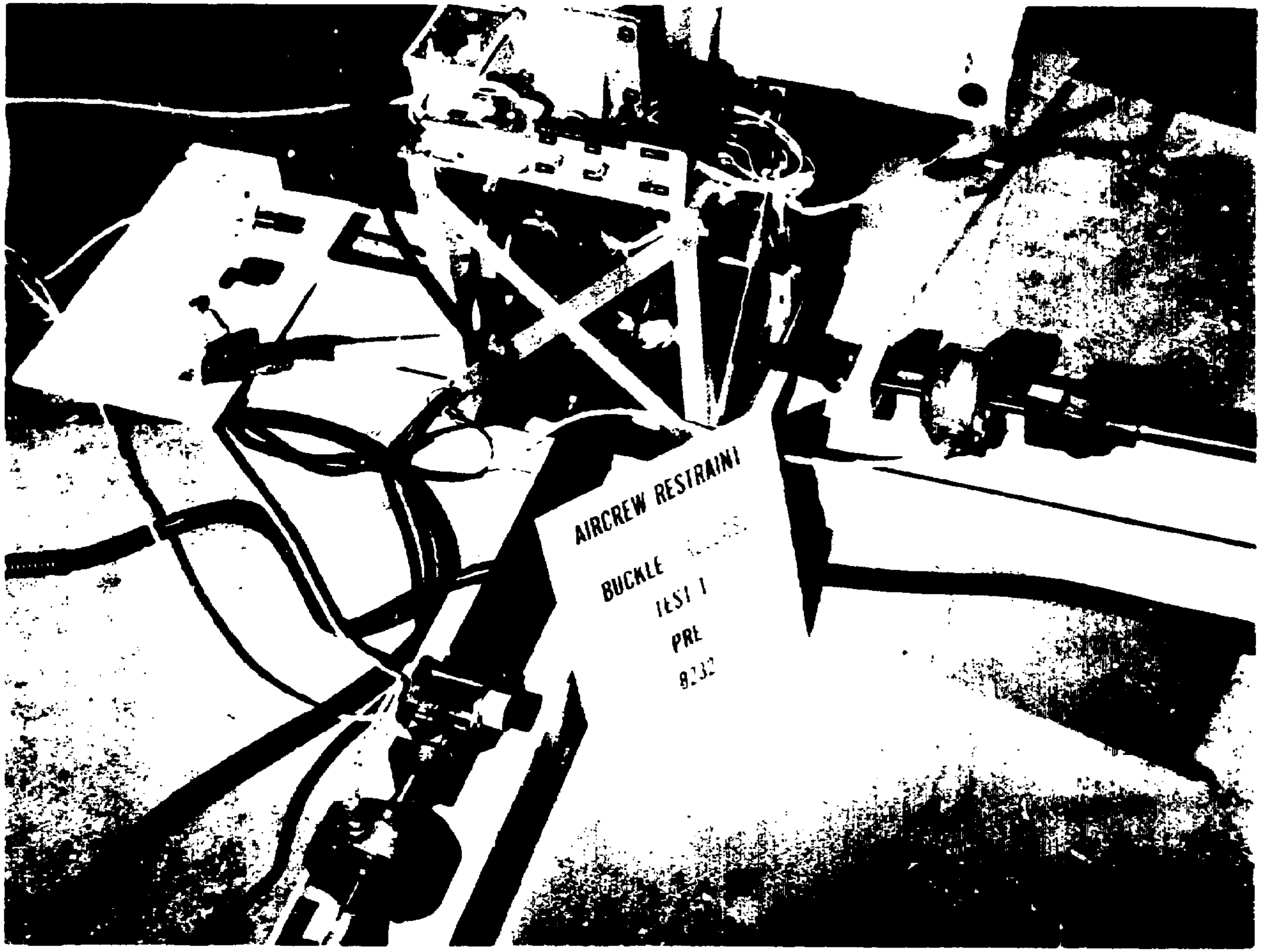


Figure 46. Buckle Release Test Configuration.

Test Fixture. When the belt loads shown were reached, the Torque Fixture was clamped to the Static Test Fixture.

A reading was then taken on the angular displacement potentiometer, and the calibrations for the load cells were recorded. The motor was energized, and after all pretest preparations had been completed, the clutch was engaged and the buckle handle rotated until all of the buckle fittings were released. The motor was eventually turned off by limit switches that were tripped when the buckle handle reached the limit of its rotation. A posttest reading was recorded for the angular displacement potentiometer, and posttest calibrations for the load cells were recorded. The hand on the Torque Fixture was then changed to permit handle rotation in the opposite direction, and the test procedure was repeated.

The first test of the buckle indicated a sequential release of the buckle fittings. It was observed that after the fittings on one side of the buckle (lap belt and shoulder strap fittings) had released, additional handle rotation was required to release the other two buckle fittings. This characteristic initially created some difficulty since it caused the buckle to be pulled out of the fixture because of the unbalanced load in the system. The problem was solved by pinning the base plate, with the buckle attached, to the Torque Fixture, and then clamping this assembly to the Static Test Fixture after the webbing preloads had been applied to the buckle fittings. This eliminated the possibility of producing an unbalanced load in the buckle which might influence the release properties of the buckle. This arrangement was used for all subsequent tests.

During each rotation of the buckle handle, a similar sequential release pattern for the fittings was observed. The left lap belt and shoulder strap fittings were the first to be released, and their separation from the buckle was essentially simultaneous. Next, after additional handle rotation, the right shoulder strap and lap belt fittings were simultaneously released from the buckle. This resulted in two distinct release events for each actuation of the buckle: one for the left side of the buckle, and one for the right side.

The test data resulting from 10 buckle tests (5 clockwise rotations and 5 counterclockwise rotations) are presented in Table 16. The two entries for release angle and torque are for the two release events that occurred during handle rotation.

After the first series of buckle release tests were completed, a second test was conducted. The test procedure was the same as that previously used to release the buckle fittings, but it was preceded by a brief loading of the lap belt to 4,000 pounds

TABLE 16. BUCKLE RELEASE DATA - PROTOTYPE BUCKLE						
Test Number	Handle Rotation	Release Angle* (deg)	Release Torque* (in. - oz)	Release Torque* (in. - lb)	Ejection of Fittings (Yes/No)	Simultaneous Release (Yes/No)
1	CW	18.0/32.0	290/144	18.0/9.0	Yes	No
2	CCW	24.8/36.0	123/92	7.7/5.8	Yes	No
3	CW	18.8/32.8	126/92	7.0/5.8	Yes	No
4	CCW	19.6/30.0	133/66	8.3/4.0	Yes	No
5	CW	18.6/33.2	145/115	9.0/7.0	Yes	No
6	CCW	19.2/32.0	126/886	7.9/5.5	Yes	No
7	CW	19.0/31.4	361/248	22.5/15.5	Yes	No
8	CCW	21.2/35.2	116/90	7.3/5.6	Yes	No
9	CW	18.8/36.4	363/223	22.6/13.9	Yes	No
10	CCW	18.4/32.4	268/247	23/15.4	Yes	No

*One entry for each release that occurred during handle rotation.

and the tie-down strap to 2,000 pounds. The 2,000-pound tie-down strap load resulted in approximately 1,050 pounds being applied to each shoulder strap fitting. This was an intermediate load selected because the tie-down strap was not strong enough to balance the shoulder harness design load of 2,000 pounds for each strap. After the 2,000-pound and 4,000-pound loads were reached, they were reduced to the preload conditions used for the previous tests. The buckle was then released once in each direction, and the data shown in Table 17 were recorded.

TABLE 17. BUCKLE RELEASE DATA* - PROTOTYPE BUCKLE WITH DESIGN LOADS						
Test Number	Handle Rotation	Release Angle** (deg)	Release Torque** (in. - oz)	Release Torque** (in. - lb)	Ejection of Fittings (Yes/No)	Simultaneous Release (Yes/No)
1	CW	26.8/38.0	443/245	27.7/15.3	Yes	No
2	CCW	26.8/38.0	511/273	31.9/17.0	Yes	No

*Test sample loaded to 4,000 pounds through lap belt fittings and 2,000 pounds in the tie-down strap, which resulted in approximately 1,050 pounds in the shoulder harness fittings.
**One entry for each release that occurred during handle rotation.

After completion of this test, the requirement that each fitting be subjected to the full design load was reexamined. The purpose of this requirement was to ensure that the buckle would release the fittings properly after they had been exposed to simulated crash loads. It was thought that the high loads carried by the fittings during an impact might cause internal deformations within the buckle that would prevent the proper release of the fittings. The test procedure specified to simulate this condition called for the design loads to be applied quasi-statically. The loads were slowly increased over relatively long periods of time until the design loads were reached. Once the design loads were attained, they were reduced to the preloads previously specified. Since this test procedure would subject the buckle to the high design loads for a much longer time period than would occur during a crash, the test was simulating a more severe condition than would occur during a crash. This implies that following this test procedure could unfavorably bias the results for an otherwise acceptable buckle. Because the buckle release test must have the loads applied quasi-statically rather than dynamically, the procedure was changed so that only two-thirds of the design loads were applied to the fittings. It was reasoned that this change resulted in a test procedure that more nearly simulated the situation being tested (i.e., buckle release after application of crash loads). After this change was made to the test procedure, the buckle release tests were performed again, and the data from this test are recorded in Table 18.

TABLE 18. BUCKLE RELEASE DATA* - PROTOTYPE BUCKLE WITH 2/3 DESIGN LOADS

Test Number	Handle Rotation	Release Angle** (deg)	Release Torque** (in. - oz)	(in. - lb)	Ejection of Fittings (Yes/No)	Simultaneous Release (Yes/No)
1	CW	33.0/34.8	568/391	47.4/32.6	Yes	No
2	CCW	29.3/40.4	923/124	76.8/10.3	Yes	No

*Test sample loaded to 2,666 pounds through lap belt fittings and 2,666 pounds in the tie-down strap, which resulted in approximately 1,385 pounds in the shoulder harness fittings.
**One entry for each release that occurred during handle rotation.

Examination of all the buckle release data indicated that the buckle handle required an average of 13-1/2 degrees of additional rotation after the first fitting was released to completely release the remainder of the fittings. The fitting release sequence was approximately the same each time the buckle was tested and was not dependent on the direction of

rotation of the handle. The left lap belt fitting would be released first, and release of the left shoulder strap fitting would immediately follow. After the buckle handle had been rotated approximately 13-1/2 additional degrees, the right shoulder harness fitting would be released just prior to or coincident with the right lap belt fitting. This problem was discussed with PSCo, and no obvious explanation or solution was discovered. The buckle which had been tested was disassembled and examined for any obvious cause of the sequential release, and none could be found. However, it was agreed to test three production rotary buckles to determine if this type of release was common to all PSCo rotary buckles or if it was just characteristic of the prototype buckle that was tested. These production buckles each had handles made from different tooling so that the effect of tooling could be evaluated.

The three buckles were designated new, obsolete, and ancient according to their vintage, and subsequently were received and tested by Dynamic Science. The results of these tests are shown in Table 19. Examination of the data from the production buckle tests along with the previous buckle release data indicated that the variation in fitting release angle was a function of the basic buckle design. Therefore, the angularity requirement for complete fitting release was reexamined along with the prototype buckle release data (Table 16).

TABLE 19. BUCKLE RELEASE DATA - PRODUCTION BUCKLES

			Release Angle (deg)						
			Lap Belt		Shoulder Strap				
Test Number	Buckle	Handle Rotation	Left	Right	Left	Right	Maximum Difference	Release Torque (in. - lb)	Fitting Ejection (Yes/No)
1	New	CCW	24.0	*	24.0	*		47.0	No
2	New	CCW	28.0	*	28.0	*		46.9	No
3	New	CW	23.2	*	23.2	*		43.9	No
4	Obsolete	CW	34.9	36.9	34.9	34.9	2.0	50.8/30.9	Yes
5	Obsolete	CW	38.0	38.0	38.0	34.8	3.2	59.6/44.9	Yes
6	Obsolete	CCW	38.7	42.4	38.7	26.7	12.0	54.2/52.4/42.9	Yes
7	Obsolete	CCW	35.3	30.3	35.3	25.0	10.3	49.1/52.4/38.7	Yes
8	Ancient	CCW	28.5	40.0	38.9	38.9	11.5	47.4/28.2/20.5	Yes
9	Ancient	CCW	27.0	36.5	36.0	36.0	8.5	48.7/24.7/15.4	Yes
10	Ancient	CW	29.6	29.6	21.6	21.6	8.0	54.2/43.8	Yes
11	Ancient	CW	27.3	24.9	24.9	21.4	6.4	58.4/36.9/29.9	Yes

*Fittings did not release.

The requirement for simultaneous fitting release was dictated to forestall the possibility that after a crash the crewman might be fully supported by the restraint system (i.e., the aircraft is inverted), and a sequential release of the buckle fittings could be potentially dangerous by releasing only one or two of the restraint system's straps. An occupant might be restrained then in a position where he would be unable to release the remaining fittings and thus would be trapped in the aircraft. Unless assistance was available, he would perish in the event of a postcrash fire. Sequential fitting release might also cause difficulties in an upright aircraft by preventing rapid egress from the aircraft.

Since sequential release of the buckle fittings is very undesirable, the simultaneous release of all fittings should be a definite requirement for the buckle. However, the exact definition of "simultaneous" needs to be established. Unfortunately, an exact interpretation of simultaneous release would demand extremely close dimensional tolerances for the pieces used in the buckle's release mechanism. This would probably result in an astronomical cost for the buckle, which is also undesirable. Therefore, some minimum release angle variation for the fittings had to be established, which would permit normal machining tolerances to be used in making the buckle's parts, and yet essentially prevent the possibility of a sequential release of the fittings.

It was found that sequential release of fittings is somewhat dependent on the buckle design, but it is largely a function of the occupant's ability to stop rotation of the buckle handle once the release sequence has been initiated. That is, a certain force must be applied to release the first fitting from the buckle, and after this occurs, natural follow-through continues rotation of the buckle handle through an additional angle. If the handle can be physically stopped before the remaining fittings are released, then variation in fitting release angle is too great. The minimum angle through which the handle can be naturally rotated (i.e., a rotation that is physically impossible to prevent) after the release of the first fitting is the maximum difference in fitting release angle that is acceptable. This angle had to be determined in order to establish an adequate control for this variable. Therefore, Dynamic Science conducted an additional series of tests to establish the maximum acceptable spread in fitting release angles.

The additional tests consisted of measuring the fitting release angles during manual operation of the buckle handle with fitting loads in the range of 0 to 100 pounds. The buckle was placed in the Static Test Fixture (DSL602), which was used to

apply the fitting loads; and without any support for the buckle other than the straps, the buckle handle was manually rotated and the fitting releases were observed. This test was conducted several times with both 50-pound and 100-pound loads on the fittings, and no sequential fitting releases were observed during any of the tests. In other words, the buckle handle was manually rotated and all fittings were released simultaneously.

Since the earlier buckle release tests had been performed with the buckle housing permanently attached to a rigid fixture, this configuration was duplicated and a buckle release test was conducted with the buckle handle manually operated. During this test, sequential release of the fittings was again observed. The left lap belt and shoulder strap fittings were released first, essentially at the same time, and after an additional handle rotation of approximately 13-1/2 degrees, the right shoulder strap and lap belt fittings were simultaneously released from the buckle.

The results of these additional tests indicated that with this buckle it is possible to manually release the fittings at different times only if the buckle housing is prevented from rotating. If the buckle housing is free to move as it would be during actual usage (i.e., supported only by the occupant and/or the restraint system's straps), it is physically impossible to sequentially release the fittings manually. This implies that the minimum angle through which the buckle handle will naturally rotate with respect to the unstablilized buckle housing (i.e., a rotation that is physically impossible to prevent) after the release of the first fitting is at least 13-1/2 degrees. Therefore, based on the results of all the buckle release tests, the maximum difference in handle rotation between release of the first and last fitting was set at 15 degrees.

An additional problem with the buckle was revealed during the buckle release tests. The problem was revealed during the test that simulated an actual crash condition by imposing the design loads before the buckle fittings were released. In this test, the tie-down strap was loaded to approximately 2,800 pounds, and one of the shoulder harness fittings prematurely pulled out of the buckle. The buckle and fittings were then visually examined, and no obvious malfunction of either unit could be seen. The fittings were then turned over to ensure the best interface between them and the buckle dogs, and the buckle was retested. An identical failure occurred again at approximately the same shoulder harness load (1,470 pounds). The fitting was immediately reengaged and retested, and a third failure occurred at a shoulder harness load of approximately 1,310 pounds.

The probable cause of this failure was determined to be a small radius on the contact surface of the prototype shoulder strap fitting which permitted the fitting to ride up on the face of the buckle latching dog, depress it by cam action, and thus be released and pulled out of the buckle. This radius would not exist on the production part because of production fabrication practices. The fittings that failed were reworked by Pacific Scientific Company and returned to Dynamic Science for further evaluation. In the retest, the shoulder fittings were each loaded to 2,000 pounds, and the removal of the radius on the fitting was judged to solve the problem of premature fitting release.

BUCKLE FITTING EJECTION TEST

The buckle was mounted on the Static Test Fixture (DSL602) with all fittings fully engaged with no load (including that which might be applied by the weight of the webbing) applied to them. The buckle handle was then manually rotated first in one direction and then the other. After each rotation of the buckle's handle, the fittings were visually inspected, and in both cases, all the buckle fittings were released from the latch dog.

DYNAMIC TESTS

The aircrew restraint system was subjected to the two dynamic tests required by the proposed specification in order to verify that it could adequately restrain a 95th percentile occupant during two impact environments that are representative of a 95th percentile survivable aircraft crash. One test was a vertical impact conducted on a drop tower, and the other test was a horizontal impact conducted on a horizontal test sled. The occupant used for these tests was a 95th percentile anthropomorphic dummy clothed with thermal underwear and equipped with a helmet, aircrew armor, and vest type survival kit. The weights for the dummy and its associated equipment are given below.

Item	Weight (lb)
Anthropomorphic Dummy (95th percentile)	212.0
Clothing (total)	7.0
Boots	4.0
Socks	0.2
Thermal Underwear	2.8
Equipment (total)	23.0
Helmet	3.3
Body Armor	17.7
Survival Vest	2.0
Total Occupant Weight	242.0

The dummy was restrained in a fixture type seat (rigid) with the test restraint system. Accelerometers and webbing load cells were used to measure restraint system loads and the acceleration response of various dummy segments, seat, and test input.

Prior to the initiation of either test, the dummy was inspected to be sure that it was in good operating condition, and its joints were adjusted to provide a 1G resistance to the movement of various limbs. Triaxial accelerometer mounts were placed in the head, chest, and pelvic area of the dummy and also on the seat pan and seat base to measure the accelerations in three

orthogonal directions. The weight of the dummy was then adjusted to 212 pounds to represent a 95th percentile Army pilot.[10] A single accelerometer was mounted in the drop cage and/or sled to measure the input pulse. Webbing load cells were placed on each of the restraint system members close to their anchor points to measure the load-time history imposed on each element of the restraint system. The restraint system to be tested was mounted on the rigid test seat and connected with the dummy in the seat. All slack was eliminated from the restraint system; the retractors were automatically locked; and the inertia reel control was set in the automatic lock position.

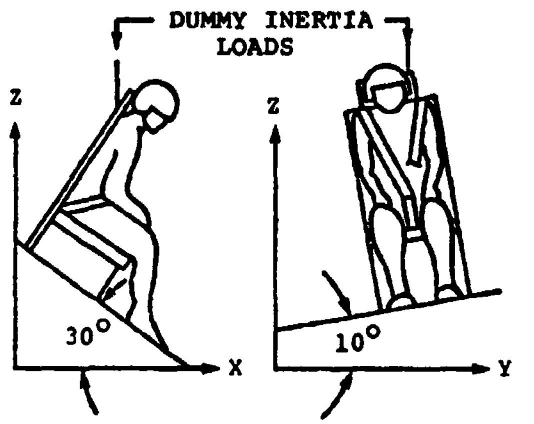
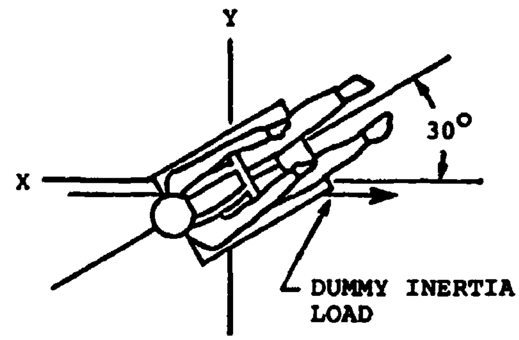
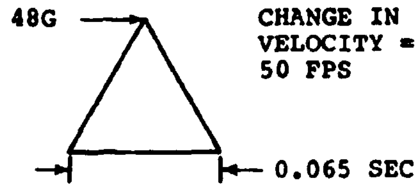
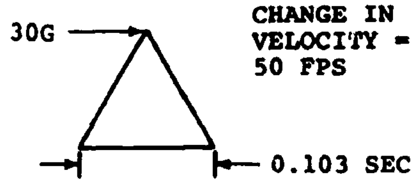
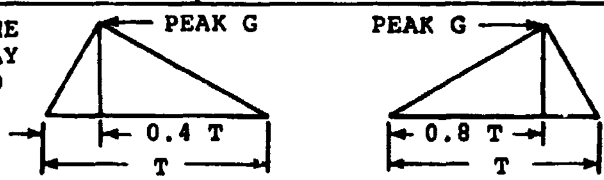
The initial conditions and input pulse specified for the two dynamic tests are shown in Table 20. For the vertical impact test, the seat containing the restrained dummy was mounted on a base that simulated the seat being positioned at a 30-degree forward pitch and 10-degree roll relative to the input deceleration vector. The velocity change required for this test was 50 feet per second over a time duration of 0.065 second with a peak deceleration of 48G. For the horizontal impact tests, the seat containing the restrained dummy was mounted on a horizontal test sled at 0-degrees pitch and roll and a 30-degree yaw attitude relative to the input deceleration vector. The specified change in velocity for this test was 50 feet per second over a time duration of 0.103 second with a peak deceleration of 30G. The deceleration waveforms required for both tests were triangular.

The configurations of the dummy and restraint system both before and after the first vertical impact are shown in Figure 47, while before and after photos of the first horizontal impact are shown in Figure 48. During each of the dynamic tests, the restraint system performed quite satisfactorily. There were no component failures, and from the final position of the dummy, it was apparent that the restraint system performed its primary function of keeping the occupant in the seat.

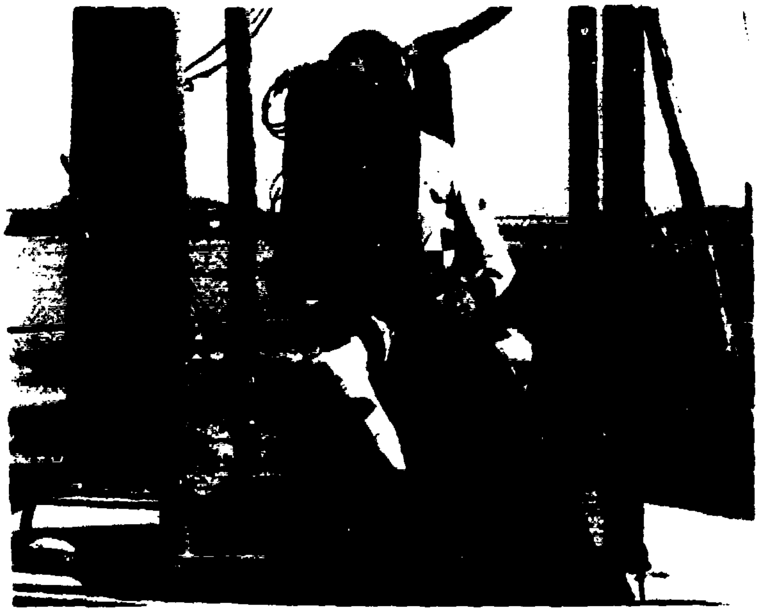
Acceleration data measured during the horizontal and vertical impacts are summarized in Table 21, while a summary of the restraint loads measured during each test is presented in Table 22. The data presented was filtered at 250 Hz in analog form and digitally filtered at 100 Hz.

10. Churchill, E., et al, ANTHROPOMETRY OF U.S. ARMY AVIATORS, USANL TR 72-52-CE, U. S. Army Natick Laboratories, Natick, Massachusetts, December 1971.

TABLE 20. DYNAMIC TEST REQUIREMENTS

TEST CONDITIONS AND SEAT ORIENTATION	
TEST 1: DOWNWARD, FORWARD, AND LATERAL LOADS	TEST 2: FORWARD AND LATERAL LOADS
	
TEST PULSE REQUIRED*	
	
*THE RISE TIME FOR THE TRIANGULAR PULSES MAY VARY BETWEEN THE TWO VALUES ILLUSTRATED (T - TIME):	

Examination of the data acquired in these tests indicated that higher than expected velocity changes were achieved, while the peak input decelerations were lower than anticipated. The peak deceleration measured in the drop tower test was 44G; in the sled test, 25G. The honeycomb stacks used for these two tests had been calibrated for peak decelerations of 48G and 30G, respectively. The velocity change measured during both tests was 55 fps, which was 5 fps greater than expected and provided



Initial Position

Final Position

Figure 47. Initial and Final Positions - First Drop Test.

Initial Position

Final Position

Figure 48. Initial and Final Positions - First Sled Test.

TABLE 21. SUMMARY OF DECELERATION DATA - TEST SERIES #1					
		Sled Test		Drop Test	
Accelerometer Location	Axis	Peak Deceleration (G)	Time (msec)	Peak Deceleration (G)	Time (msec)
Sled	Resultant	24.9	75	44.3	50
D. Head	Longitudinal (X)	68.5	83	58.1	68
D. Head	Lateral (Y)	*		13.9	58
D. Head	Vertical (Z)	20.9	93	52.3	29
D. Head	Resultant	68.6	83	60.2	67
D. Chest	Longitudinal (X)	38.3	76	27.7	58
D. Chest	Lateral (Y)	21.1	84	71.5	57
D. Chest	Vertical (Z)	26.4	83	14.4	64
D. Chest	Resultant	47.4	83	75.4	57
D. Pelvis	Longitudinal (X)	24.0	81	41.3	58
D. Pelvis	Lateral (Y)	34.5	77	15.9	55
D. Pelvis	Vertical (Z)	31.9	82	62.1	62
D. Pelvis	Resultant	51.1	79	74.8	62
Seat Pan	Longitudinal (X)	20.7	78	50.3	28
Seat Pan	Lateral (Y)	14.2	74	22.2	57
Seat Pan	Vertical (Z)	1**		34.3	27
Seat Pan	Resultant	24.4	79	56.2	27
Head Severity Index (X & Z axes)		553		476	
Chest Severity Index		392		689	

*Faulty Data Channel
**Average Deceleration

a higher energy impact than was required by the specification. Both tests were successful in that there was no failure of any of the restraint system members.

The cause of the lower than expected input decelerations was suspected to be the manner in which the honeycomb stacks were calibrated for the input deceleration pulses. The honeycomb stacks were calibrated with both the drop cage and sled ballasted to represent the total weight of the test item, including the restraint system and instrumented dummy. It is believed that the elastic coupling between the dummy and the

TABLE 22. SUMMARY OF RESTRAINT SYSTEM LOADS - TEST SERIES #1

Load Cell Location	Sled Test		Drop Tower Test	
	Peak Load (lb)	Time (msec)	Peak Load (lb)	Time (msec)
Left Lap Belt	3175	80	810	87
Right Lap Belt	2240	77	1850	67
Left Shoulder Strap	168	68	110	71
Right Shoulder Strap	1730	89	1785	67
Tie-down Strap	*		1030	191
Refl. Strap - L Anchor	*		863	89
Refl. Strap - L Reel	376	70	193	59
Refl. Strap - R Anchor	307	69	166	57
Refl. Strap - R Reel	1346	93	826	92

*Faulty Data Channel

rigid seat due to the restraint system caused the lower peak decelerations by virtue of the phase lag in the effective weight of the test device, since the dummy is essentially unrestrained during the first part of the sled impact test. This effectively reduces the weight of the sled and increases the deceleration imposed by a given section of the honeycomb during the initial crushing of the honeycomb stack. Consequently, the sled's velocity change during the early crash sequence is greater than its velocity change during the calibration test, which produces slightly less total penetration into the stack, thus causing the phenomena noticed in these tests. One way to resolve this problem is to calibrate the honeycomb stacks with an anthropomorphic dummy restrained by a representative restraint system. This configuration would better duplicate the test conditions and should produce a match of dynamics which would ensure successful achievement of the desired input deceleration.

Since it is always desirable technically to perform more than a minimum number of tests to demonstrate the performance of critical products, it was recommended that the two impact tests (horizontal and vertical) be rerun with the required input decelerations imposed on the restraint system. Testing in this manner would produce a series of tests with ascending degrees of imposed load severity, thereby providing a wider spectrum of performance data for evaluation and demonstration.

The recommendation was approved and the dynamic tests were rerun. The dynamic retests (Test Series #2) were conducted using the previously tested restraint systems, since they had not been damaged, and the same test procedure except for calibration of the honeycomb stacks. For the honeycomb calibration tests, an anthropomorphic dummy was placed in the seat and restrained by a standard military restraint system.

In the second drop tower test, a peak input deceleration of 51.5G was measured (48G was required); however, the tie-down strap anchor broke at the webbing loop into two pieces during the impact. The initial and final positions of the dummy and restraint system for this test are presented in Figure 49. A preliminary inspection of the failure indicated that the fitting was bent forward and subsequently fractured due to the loading that it incurred through the tie-down strap as a result of the dummy's moving forward in the seat during impact.

The peak input deceleration reached in the second sled test was 33.5G, and during the impact the rotary buckle failed by releasing all of the fittings. This failure resulted in the dummy's moving forward out of the seat and onto the test sled. The positions of the dummy and restraint system before and after the impact are shown in Figure 50. The buckle and fittings were examined immediately after the test, and it appeared that the fittings were simply pulled out of the buckle by the impact loads of the respective straps.

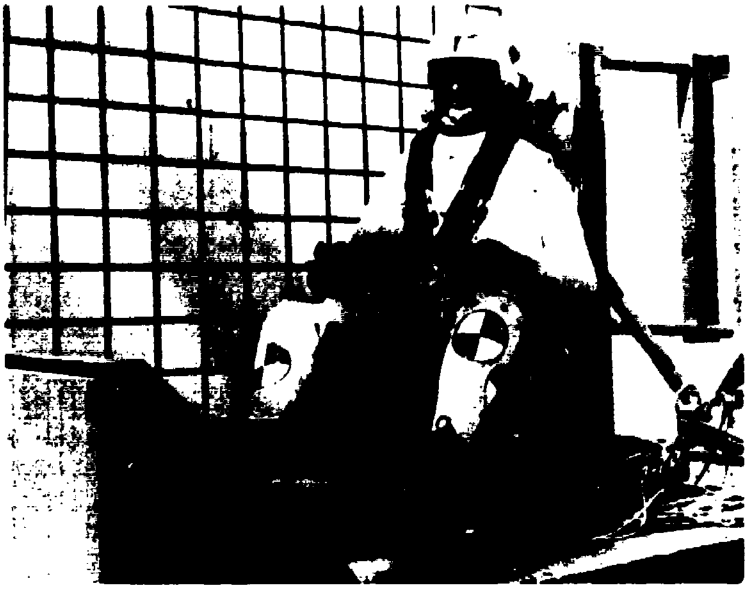
The buckle was relatively undamaged, although operation of the handle was somewhat sluggish, and all of the fittings were deformed at their interface with the buckle's locking dogs. In addition, both lap belt fittings were noticeably bent inward, with the right lap belt fitting bent the furthest (about 25 degrees), and the left shoulder strap fitting slightly bent.

It should be emphasized that the failures occurred during full load retesting of once-tested restraint systems. Even though these systems are not designed for more than one loading, the results of the dynamic retests (Test Series #2) served to illustrate the potential weaknesses of the restraint system design, and to point up areas where design improvements could be made.

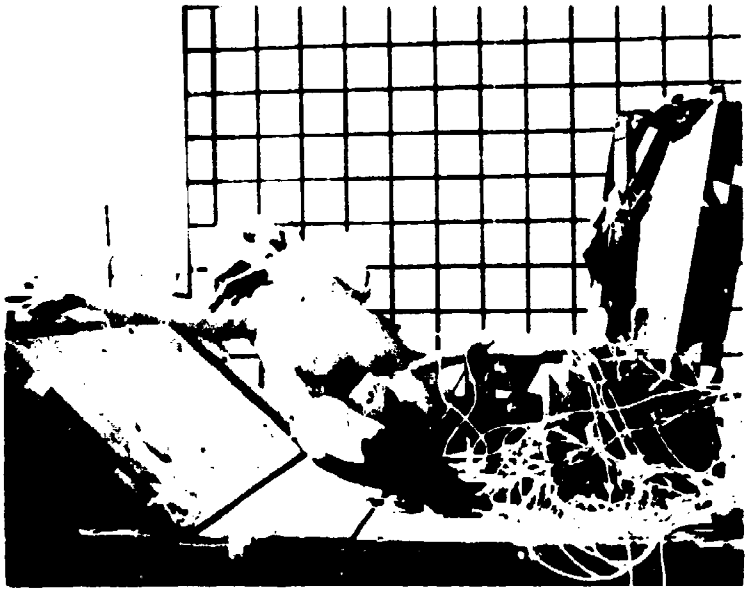
Initial Position

Final Position

Figure 49. Initial and Final Positions - Second Drop Test.



Initial Position



Final Position

Figure 50. Initial and Final Positions - Second Sled Test.

These areas were discussed with Pacific Scientific Company, and a plan was made to obtain additional restraint system hardware and to dynamically test it in accordance with the specification's requirements. The failure of the tie-down strap anchor during the drop tower test was caused by bending the anchor forward and inducing fracture of the fitting at the webbing loop. It was obvious from the results of the dynamic test that the fitting needed to be redesigned to be capable of carrying a more universal load. It was decided that the new design should be a suitcase handle type of fitting that would carry the design load of the tie-down strap (2,500 pounds) in any direction. The failure of the rotary buckle (unactivated release of buckle fittings) was found to be caused by inadequate engagement between the buckle plug-in fittings and the locking dogs. To correct this inadequacy, a redesign of the buckle was required and several possible approaches (listed below) were discussed:

- High Lift Dog
- Longer Dog
- Softer Dog Material

PSCo examined each of these approaches, and the high lift was selected as the one that would provide the best solution to the buckle problem. PSCo subsequently incorporated these design changes by refurbishing two complete aircrew restraint systems and delivered them to Dynamic Science for further dynamic testing.

The third series of dynamic tests with the refurbished restraint systems was conducted using the same test procedures previously described, and successful results were achieved. The peak input decelerations and the velocity changes for the two tests were:

	Drop Test	Sled Test
Peak Deceleration, G	53.1	29.7
Velocity Change, ft/sec	60.2	53.4

The aircrew restraint system performed quite satisfactorily during each of these impact tests (Test Series #3). There were no hardware failures, and minimal permanent body displacements were observed in the final position of the dummy.

The positions of the restraint system and dummy before and after the third drop test are shown in Figure 51, while the initial and final positions for the third sled test are shown in Figure 52. A summary of the deceleration data measured during the third series of impact tests is presented in Table 23. The peak deceleration and the time after impact that they occurred are shown. In addition, the peak restraint system loads measured and their times of occurrence are presented in Table 24. Time response plots of the data summarized in these tables are presented in Appendix D. The data presented was filtered at 250 Hz in analog form and at 100 Hz in digital form.

Initial Position

Final Position

Figure 51. Initial and Final Positions - Third Drop Test.

Initial Position

Final Position

Figure 52. Initial and Final Positions - Third Sled Test.

TABLE 23. SUMMARY OF DECELERATION DATA - TEST SERIES #3					
Accelerometer Location	Axis	Sled Test		Drop Test	
		Peak Deceleration (G)	Time (msec)	Peak Deceleration (G)	Time (msec)
Sled/Drop Cage	Resultant	29.7	85	53.1	52
D. Head	Longitudinal (X)	104.7	101	25.8	109
D. Head	Lateral (Y)	56.3	200	11.1	105
D. Head	Vertical (Z)	54.0	94	82.3	61
D. Head	Resultant	109.6	101	82.6	61
D. Chest	Longitudinal (X)	142.8	91	41.3	53
D. Chest	Lateral (Y)	31.4	90	5.9	25
D. Chest	Vertical (Z)	40.7	88	60.2	63
D. Chest	Resultant	147.2	91	66.2	63
D. Pelvis	Longitudinal (X)	29.1	92	36.1	53
D. Pelvis	Lateral (Y)	44.9	95	17.0	71
D. Pelvis	Vertical (Z)	31.4	89	60.4	81
D. Pelvis	Resultant	57.2	95	61.6	81
Seat Pan	Longitudinal (X)	22.3	87	27.7	51
Seat Pan	Lateral (Y)	13.4	83	7.0	51
Seat Pan	Vertical (Z)	1*		47.9	51
Seat Pan	Resultant	25.8	87	55.8	51
Head Severity Index (X & Z axes)		1662.8		775.9	
Chest Severity Index		3242.2		631.3	
Pelvis Severity Index		401.6		384.1	
*Average Deceleration					

TABLE 24. SUMMARY OF RESTRAINT SYSTEM LOADS - TEST SERIES #3

Load Cell Location	Sled Test		Drop Tower Test	
	Peak Load (lb)	Time (msec)	Peak Load (lb)	Time (msec)
Left Lap Belt	3207	94	*	
Right Lap Belt	3043	95	1408	75
Left Shoulder Strap	480	93	655	83
Right Shoulder Strap	1136	92	1407	63
Tie-Down Strap	812	131	304	85
Refl. Strap - L Anchor	*		620	75
Refl. Strap - R Reel	1444	103	637	76
Refl. Strap - R Anchor	*		*	
Refl. Strap - L Reel	272	85	311	79

*Faulty Data Channel

CONCLUSIONS AND RECOMMENDATIONS

This report documents the evolution and evaluation of a forward-facing aircrew restraint system that challenges the practical limits of current restraint system technology. Restraint systems fabricated within the present state of the art successfully met all test requirements, although the static test requirements were the most stringent ever attempted and the dynamic test conditions were equally harsh. Such exacting criteria are necessary, however, if adequate occupant protection is to be provided throughout the range of survivable accidents. The results of this program indicate that injury and fatalities can be significantly reduced in potentially survivable accidents involving future Army aircraft, if the aircraft are equipped with restraint systems possessing the properties and capabilities of the system discussed in this report.

The aircrew restraint system developed consists of a lap belt assembly which is automatically adjusted for both length and preload by retractors. The shoulder harness assembly includes the reflected strap inertia reel concept and therefore provides lateral load paths which could greatly increase lateral restraint. Further the additional load paths reduce the longitudinal motion and decelerations of the occupant. These two effects, of course, reduce the possibility of injury due to secondary impact of the upper torso and head with surrounding structure. During loading the lap belt is maintained in its proper position through use of a fixed length tie-down strap which attaches it to the seat pan; consequently, shoulder harness loads cannot lift the lap belt up over the iliac crests. Submarining of the lower pelvis under the belt is thereby eliminated, minimizing the possibility of internal and spinal injuries. Further, the placement of the lap belt with respect to its seat pan connection improves its ability to resist the tendency for submarining. The single-point release buckle is a rotary release type that is easy to operate but particularly resistive to inadvertent opening. The webbing is a special low-elongation polyester webbing developed to reduce dynamic overshoot, plus minimizing both motion and loading on the occupant. The webbing widths have been optimized to provide adequate load distribution, low weight, and minimal thermal problems; padding has been added under the shoulder harness and buckle to improve the overall comfort of the system.

A comparison of the new aircrew restraint system weight with that of standard military restraint systems now being used is shown in the following table.

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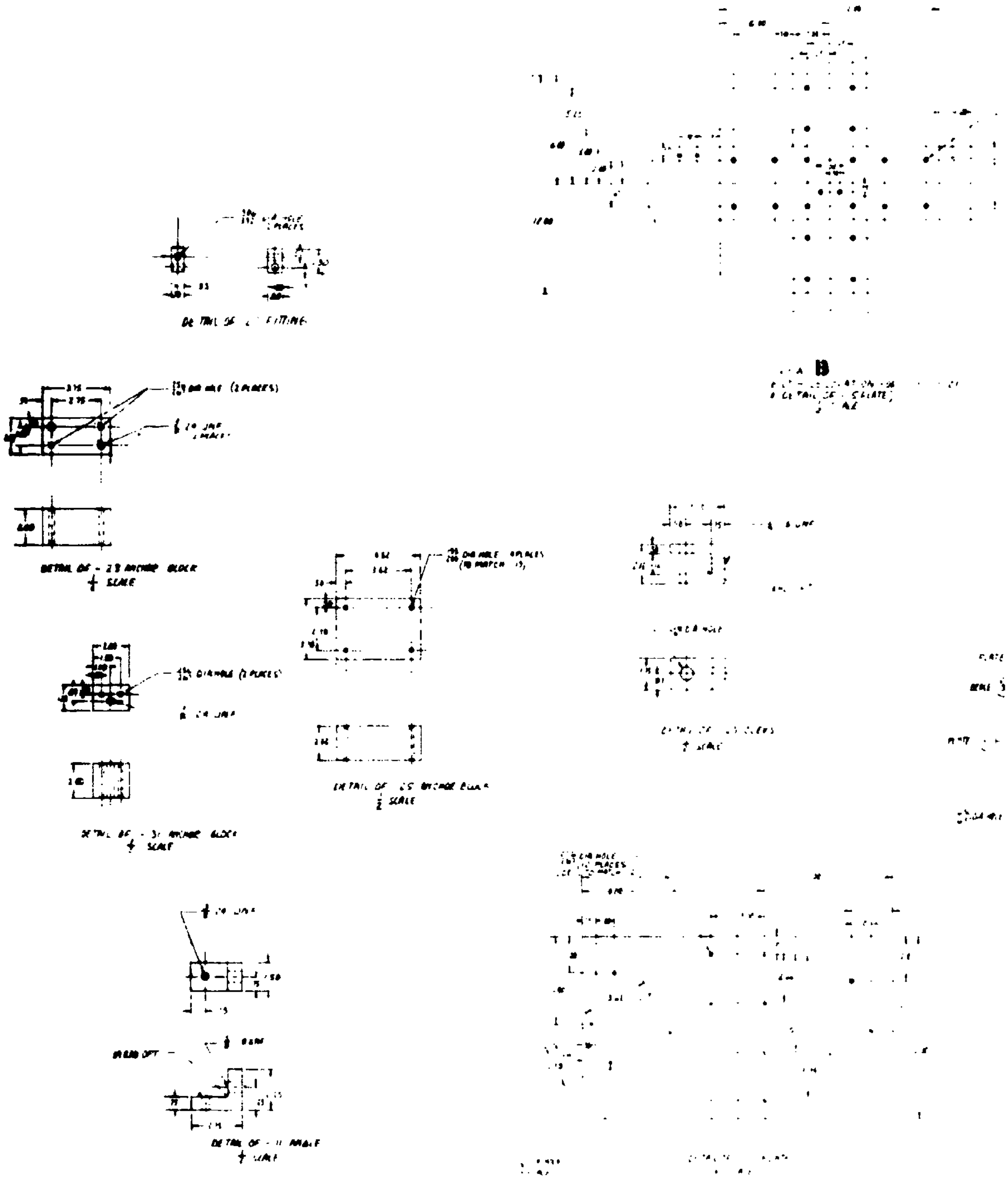
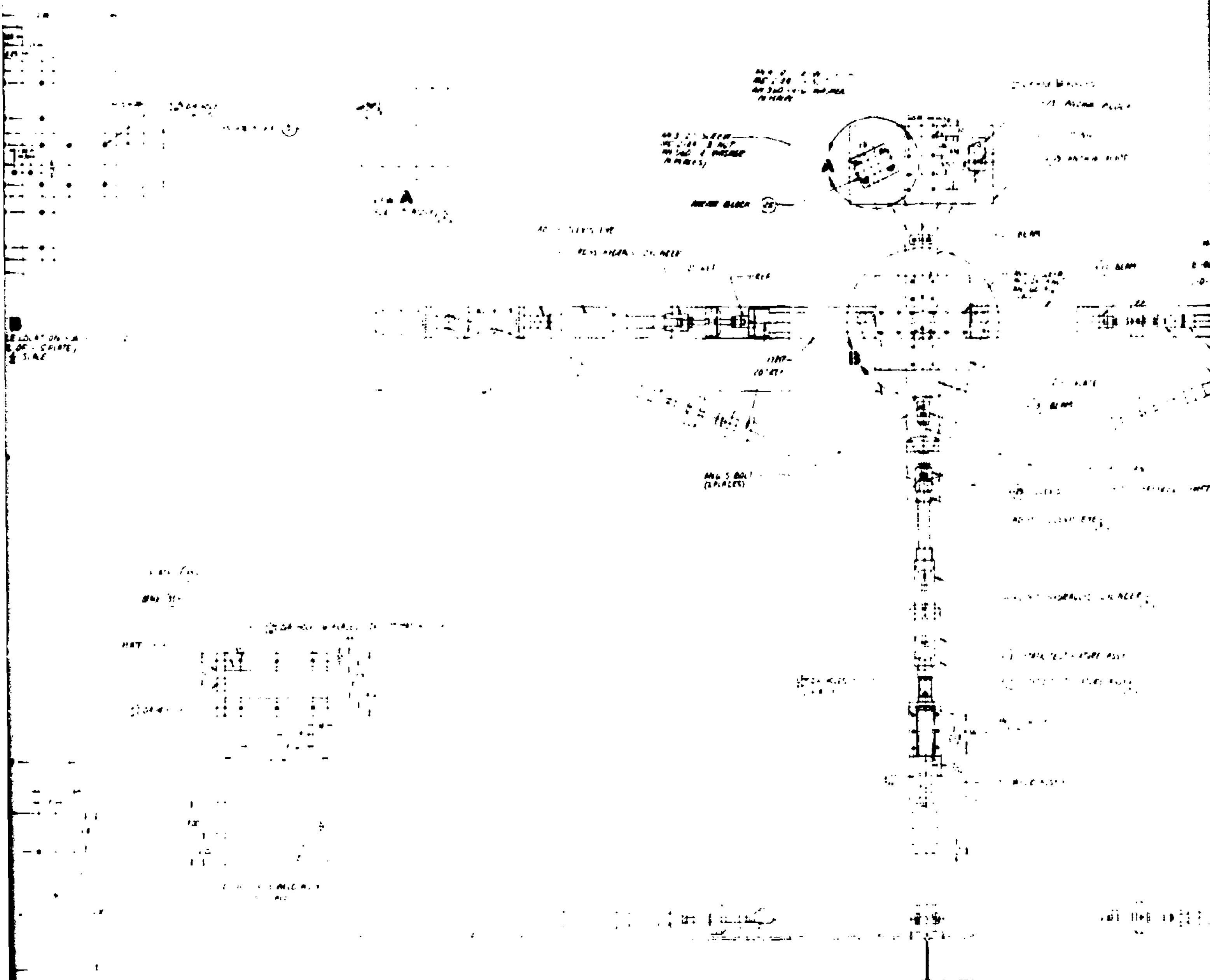
SYSTEM WEIGHT COMPARISON
(Pounds)

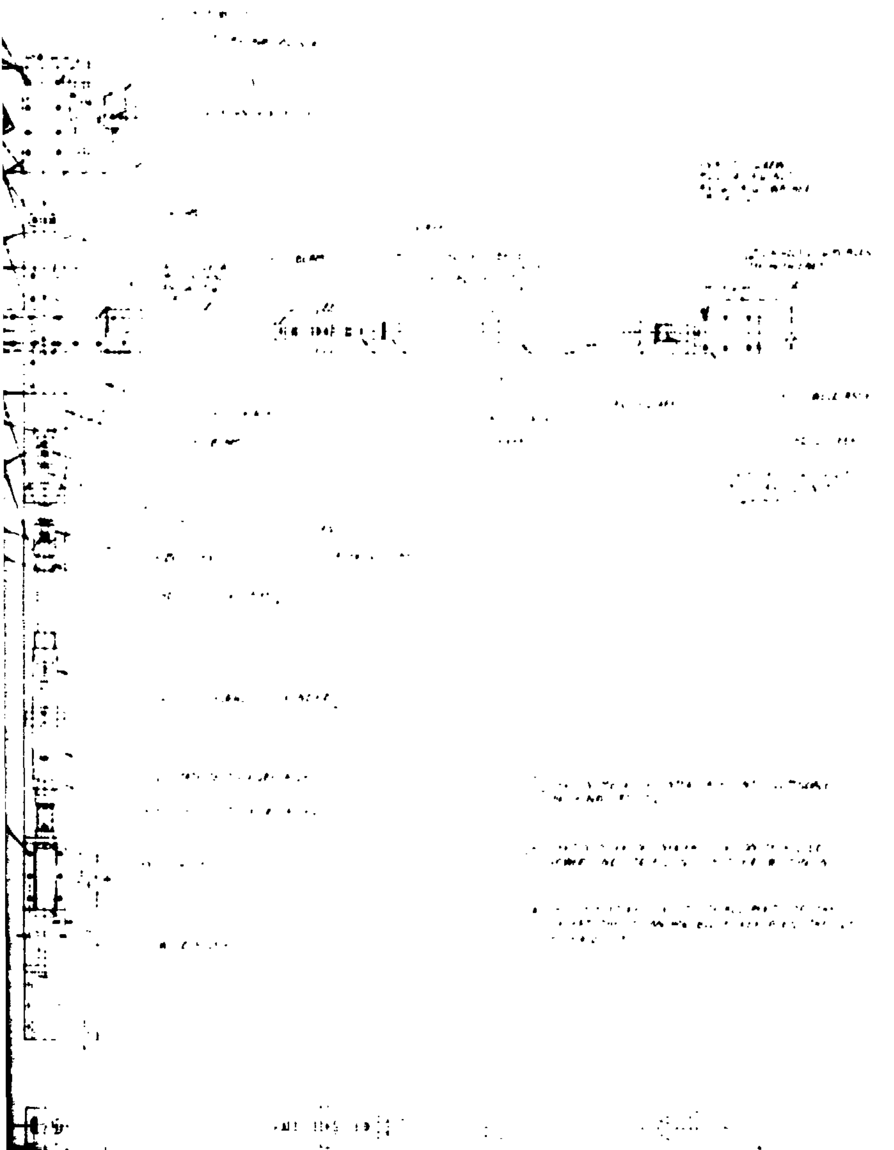
Component	New System	STD System	STD System Two Reels and Tie-down
Lap Belt	2.25	2.06	2.06
Shoulder Harness	1.54	1.06	1.06
Inertia Reel	2.95	1.10	2.20
Buckle	0.92	-	-
Tie-down Strap	0.20	-	0.20
Control Cable and Handle	0.64	0.64	0.64
	8.50	4.86	6.16

Since the new system uses dual inertia reels in conjunction with a reflected strap shoulder harness, three columns of data are presented. For comparison purposes the first column shows the weight of the major components of the new system, the second column shows the weight of the standard military restraint system, and the third column shows the weight of the standard military system with two reels and tie-down strap. This table illustrates that the new aircrew restraint system compares quite favorably with the systems now in use with a markedly increased capacity to provide protection to Army aircrewmen. The new inventory of Army aircraft, including the Utility Tactical Transport Aircraft System (UTTAS), and the Advanced Attack Helicopters (AAH) is being procured to the requirements of the combined seat and restraint specification, MIL-S-58095(AV). The system described in MIL-S-58095(AV) is an improvement over that presently used in existing aircraft; however, at best it should be considered an interim system to span the time between the old (obsolete) system and the new system developed and defined in the proposed specification MIL-R-XXXX(AV). Since the results of this program demonstrate that restraint system hardware that complies with the specification can be built within the existing state of the art, it is recommended that the proposed specification be upgraded to that of a standard military specification and used to procure aircrew restraint systems for the new aircraft (UTTAS and AAH) at the production stage and for all existing aircraft as soon as economics permit.

APPENDIX A
TEST FIXTURE DRAWINGS



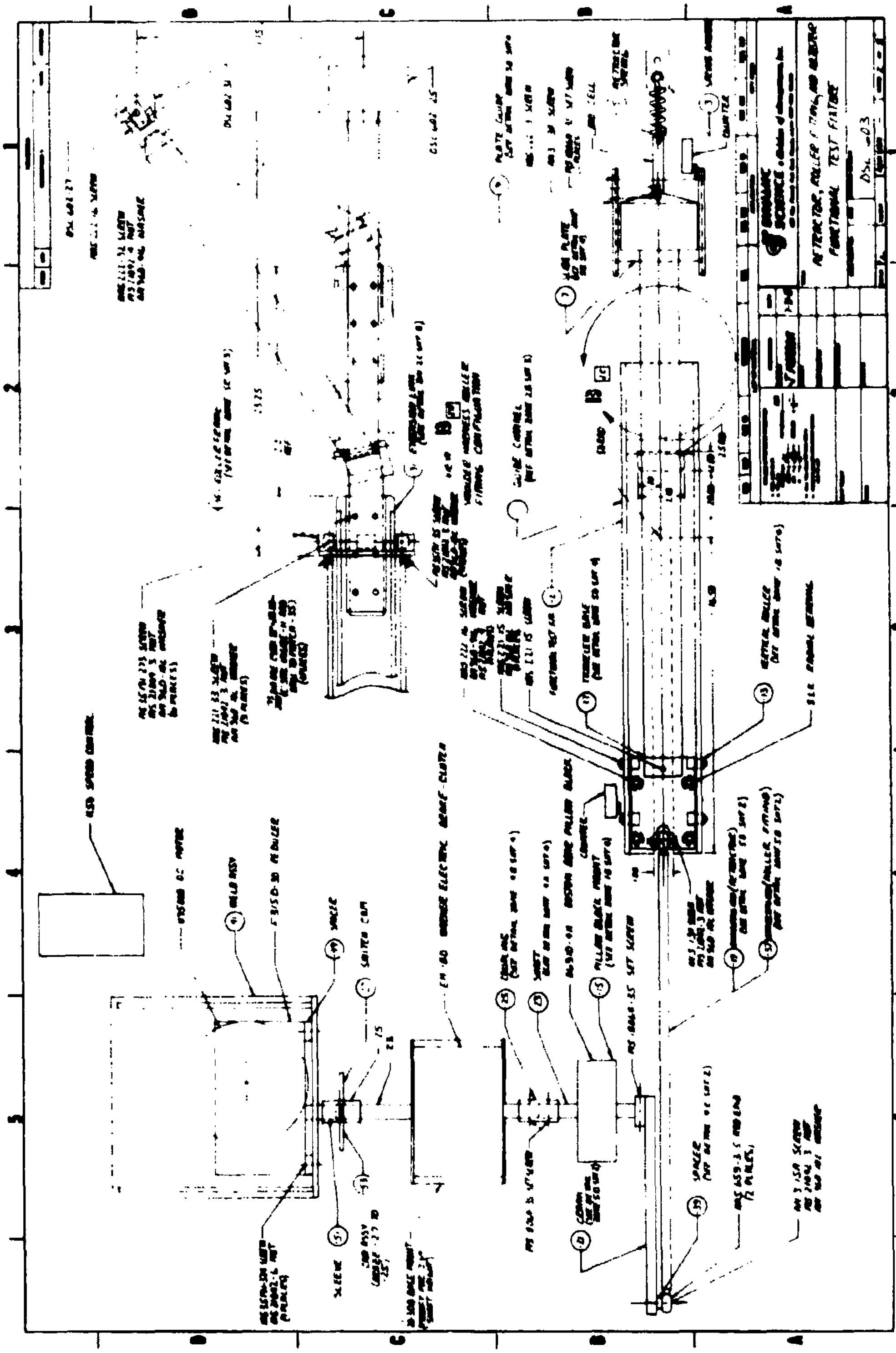

ANCHOR BLOCK (26)
BEAM
A
B

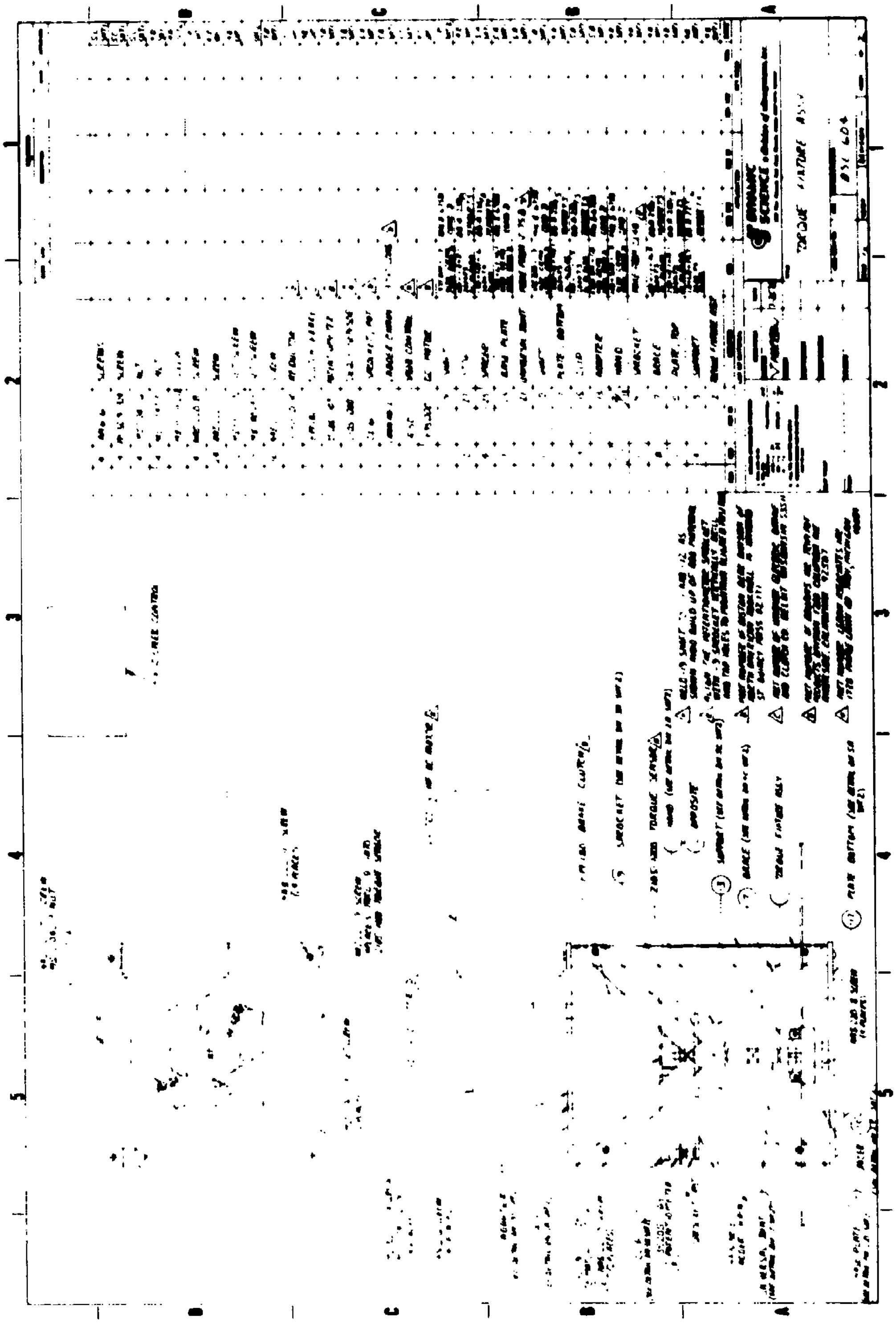


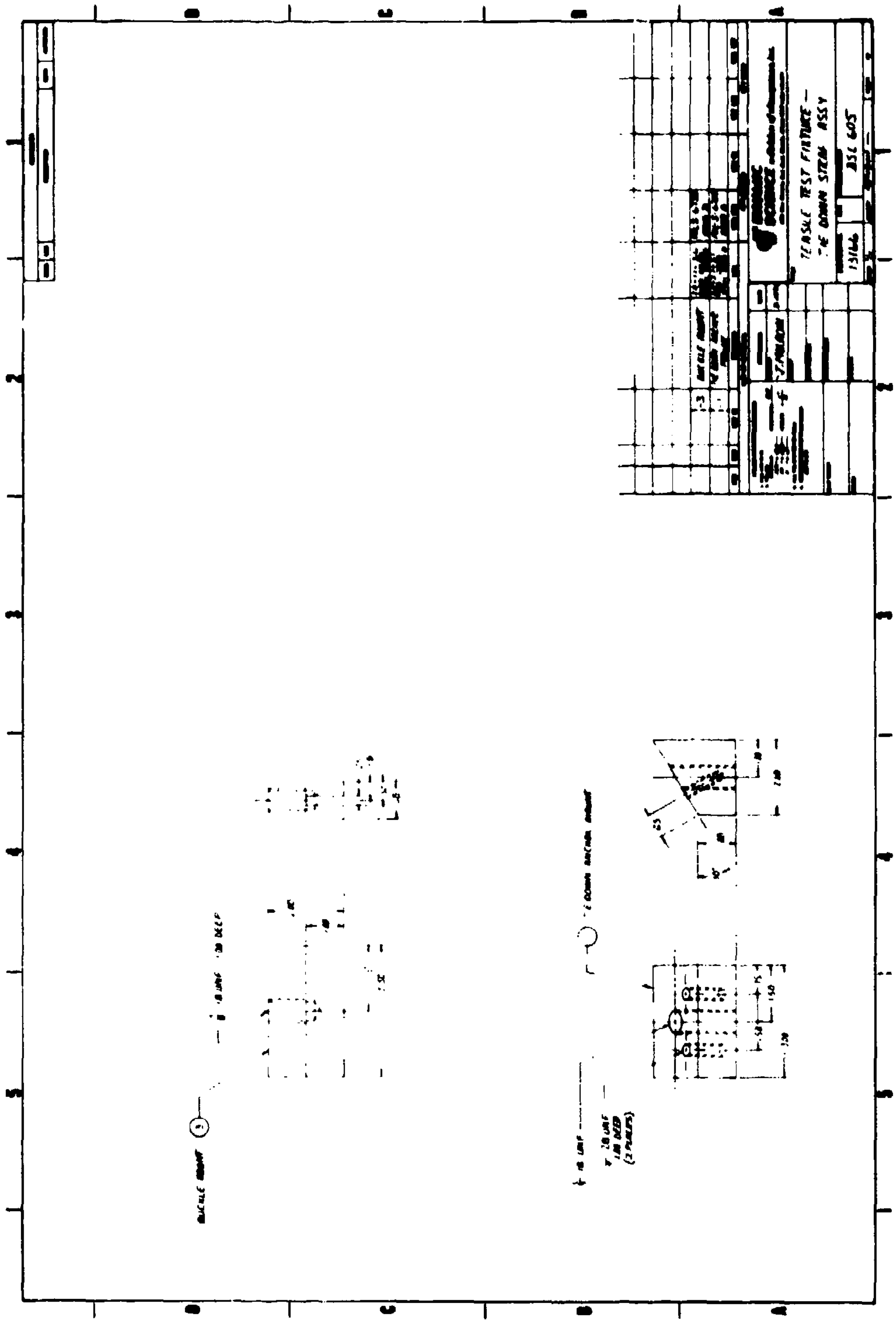
Nomenclature
WASHER
WASHER
NUT
NUT
NUT
CLEVIS PIN
BOLT
BOLT
[illegible]
[illegible]
[illegible]
[illegible]
PLATE
[illegible]
[illegible]
LOAD CELL
CLEVIS EYE
HYDRAULIC CYLINDER
PLATE
BRACE
ANCHOR BLOCK
CLEVIS
FITTING
ANCHOR BLOCK
ANCHOR BLOCK
BEAM
ANCHOR PLATE
BEAM
PLATE
BEAM
ANGLE
TIE ROD
WELD ASSY
STATIC TEST FIX ASSEMBLY
DYNAMIC TEST FIX ASSEMBLY

DYNAMIC SCIENCE a division of [illegible] Inc.

[illegible] HARNESS





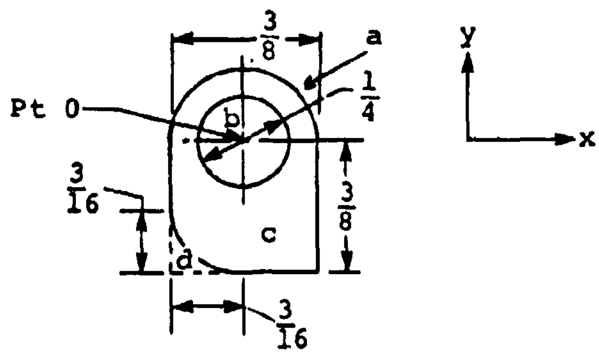

TENSILE TEST FIXTURE —
BSL 605
13166

APPENDIX B

ACCELERATION RESISTANCE ANALYSIS - ADJUSTER

The objective of this analysis is to demonstrate that the cam of the adjuster will not release when the adjuster is subjected to an acceleration of 35G along an axis that could cause the adjuster to unlock. For this analysis it is assumed that there is no tension load in the webbing.

The geometry of the adjuster is:

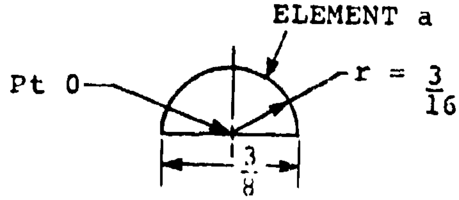


The analysis will illustrate that an acceleration of 35G in the x direction will not cause the cam to rotate about Pt 0 against the minimum restraining torque of the release spring, which has been measured at 0.781 inch-pound.

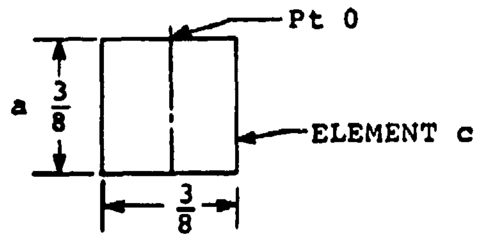
The mass moment of inertia of cam is

$$I_{cam} = I_a + I_c - I_b - I_d$$

where I_a is the mass moment of element a



and I_c is the mass moment of element c



Calculate I_a:

$$I_a = \frac{1}{2} m_a r^2$$

where $M_a = \frac{\pi r^2}{2} 1 \cdot \rho$

$l = 1.938$ in.

$\rho = 2.59 \; 10^{-4} \; \frac{\text{lb-sec}^2}{\text{in.}^4}$

$m_a = 2.78 \cdot 10^{-5} \; \frac{\text{lb-sec}^2}{\text{in.}}$

Now $\quad I_a = \frac{2.78 \times 10^{-5}}{2} \times (0.188)^2$

$I_a = \underline{\underline{4.92 \cdot 10^{-7}}}$ lb-sec^2-in.

Calculate I_c:

$$I_c = \frac{5 \; M_c a^2}{12}$$

where $a = .375$ in.

$$m_c = a^2 \cdot 1 \cdot \rho$$

$$m_c = 7.06\ 10^{-5}\ \frac{\text{lb-sec}^2}{\text{in.}}$$

Now $I_c = \dfrac{5 \times (7.06 \times 10^{-5}) \times (0.375)^2}{12}$

$$I_c = \underline{\underline{4 \cdot 1 \cdot 10^{-6}}}\ \text{lb-sec}^2\text{-in.}$$

Calculate I_b:

$$I_b = \frac{1}{2} m_b r^2$$

where $r = 0.125$ in.

$$m_b = \pi r^2 \cdot 1 \cdot \rho$$

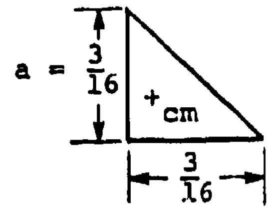
$$m_b = 2.46 \cdot 10^{-5}\ \frac{\text{lb-sec}^2}{\text{in.}}$$

Now $I_b = \dfrac{(2.46 \cdot 10^{-5})}{2} \cdot (0.125)^2$

$$I_b = \underline{\underline{1.92\ 10^{-7}}}\ \text{lb-sec}^2\text{-in.}$$

Calculate I_d:

Cross-sectional area for element d (approximate)



$$I_d = I_{dcm} + I_{dto}$$

$$I_{dcm} = \frac{m_d}{9}\, a^2$$

where $m_d = \frac{a^2}{2} \cdot \rho$

$$m_d = 4.58\ 10^{-6}\ \frac{\text{lb-sec}^2}{\text{in.}}$$

Now $I_{dcm} = \frac{(4.58 \cdot 10^{-6})}{9} \cdot (0.188)^2$

$$I_{dcm} = 1.8 \cdot 10^{-8}\ \text{lb-sec}^2\text{-in.}$$

and $I_{dtr} = m_d\, r^2$

where $r^2 = (0.375 - 0.063)^2 + (0.063)^2$

$$r^2 = 1.01 \cdot 10^{-1}\ \text{in.}^2$$

$$I_{dtr} = 4.63 \cdot 10^{-7}\ \text{lb-sec}^2\ \text{in.}$$

Therefore,

$$I_d = 1.8 \cdot 10^{-8} + 4 \cdot 63 \cdot 10^{-7}$$

$$I_d = \underline{\underline{4 \cdot 81 \cdot 10^{-7}}} \text{ lb-sec}^2\text{-in.}$$

Now $I_{cam} = I_a + I_c - (I_b + I_d)$

$$I_{cam} = \underline{\underline{3.92 \cdot 10^{-6}}} \text{ lb-sec}^2\text{-in.}$$

$$m_{cam} = m_a + m_c - (m_b + m_d)$$

$$m_{cam} = \underline{\underline{6.92 \cdot 10^{-5}}} \ \frac{\text{lb-sec}^2}{\text{in.}}$$

Determine the radius of gyration - r

$$I_{cam} = m_{cam}\, r^2$$

$$r^2 = I_{cam}/m_{cam}$$

$$r^2 = 0.567 \cdot 10^{-1} \text{ in.}^2$$

$$r = \underline{\underline{0.238}} \text{ in.}$$

The torque (T) resulting from an applied acceleration of 35G is

$$T = m_{cam} \cdot r \cdot 35 \cdot (386)$$

$$T = \underline{\underline{.222}} \text{ in.-lb}$$

The minimum restraining torque measured for the release spring is greater than the expected cam torque of .222 in.-lb. Therefore, the adjuster will not release the webbing when subjected to an acceleration of 35G. The safety margin for adjuster release is

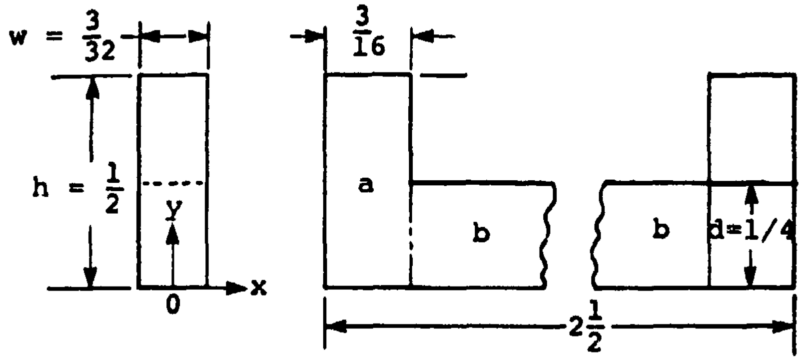
$$\frac{0.781}{0.222} = \underline{\underline{3.52}}$$

APPENDIX C

ACCELERATION RESISTANCE ANALYSIS - RETRACTOR

The purpose of this analysis is to show that the retractor's lock bar will not release when an acceleration of 35G is applied to the retractor along an axis that could cause the retractor to unlock. For this analysis it is assumed that there is no tension load in the webbing.

The geometry of the lock bar is:



The analysis will demonstrate that an acceleration of 35G along the x axis can not cause the cam to rotate about Pt 0 against the minimum restraining torque of the release spring. This torque was determined by measurement to be 0.168 in.-lb.

The mass moment of inertia of the lock bar is

$$I_L = 2 \cdot I_a + I_b$$

where I_a and I_b are the mass moments of elements a and b respectively.

Calculate I_a:

$$I_a = \frac{m_a w^2}{12} + \frac{m_a h^2}{3}$$

where $m_a = h \cdot w \cdot l\, \rho$

$$l = 0.188 \text{ in.}$$

$$\rho = 2.59 \cdot 10^{-4} \frac{\text{lb-sec}^2}{\text{in.}^4}$$

$$m_a = 2.29 \cdot 10^{-6} \frac{\text{lb-sec}^2}{\text{in.}}$$

Therefore, $$I_a = \frac{(2.29 \cdot 10^{-6}) \cdot (0.094)^2}{12} + \frac{(2.29 \cdot 10^{-6}) \cdot (0.5)^2}{3}$$

$$I_a = \underline{\underline{0.193 \cdot 10^{-6}}} \text{ lb-sec}^2\text{-in.}$$

Calculate I_b:

$$I_b = \frac{m_b w^2}{12} + \frac{m_b d^2}{3}$$

where $d = h - 1/4 = 0.25$ in.

and $m_b = d \cdot w \cdot l\, \rho$

$$l = 2.125$$

$$m_b = 0.130 \cdot 10^{-4}$$

Therefore, $I_b = \underline{\underline{0.280 \cdot 10^{-6}}}$ 15-sec^2-in.

Now $$I_L = 2 \cdot I_a + I_b$$

$$I_L = 2\ (0.193 \cdot 10^{-6}) + (0.280 \cdot 10^{-6})$$

$$I_L = \underline{\underline{0.666 \cdot 10^{-6}}}\ \text{lb-sec}^2\text{-in.}$$

and $$m_L = 2 \cdot m_a + m_b$$

$$m_L = \underline{\underline{0.175 \cdot 10^{-4}}} \cdot \frac{\text{lb-sec}^2}{\text{in.}}$$

Determine the radius of gyration - r:

$$I_L = m_L \cdot r^2$$

$$r^2 = I_L/m_L$$

$$r^2 = 0.427 \cdot 10^{-1}\text{in.}^2$$

$$r = \underline{\underline{0.195}}\ \text{in.}$$

The torque (T) resulting from an applied acceleration of 35G is

$$T = m_L \cdot r \cdot 35 \cdot 386$$

$$T = \underline{\underline{0.0461}}\ \text{in.-lb}$$

The lock bar release spring generates a minimum restraining torque of 0.168 in.-lb, which is greater than the torque of 0.0461 in.-lb that an acceleration of 35G could cause. Therefore, the retractor's lock bar will not release the webbing

spool when the retractor is subjected to an acceleration of 25G. The safety margin for the lock bar release is

$$\frac{0.168}{0.0461} = 3.64$$

APPENDIX D

ACCELERATION AND FORCE/TIME HISTORIES,
TEST SERIES #3

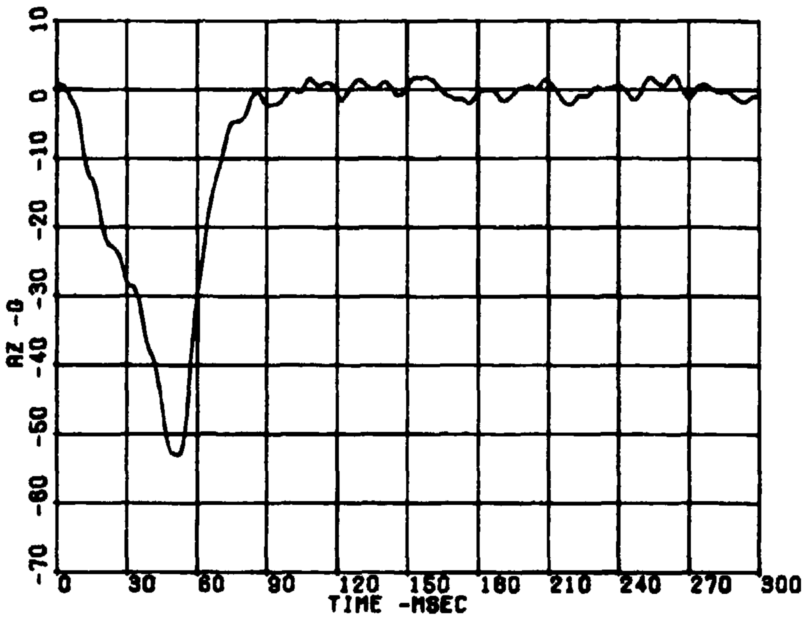


Figure D-1. Drop Test: Input Acceleration.

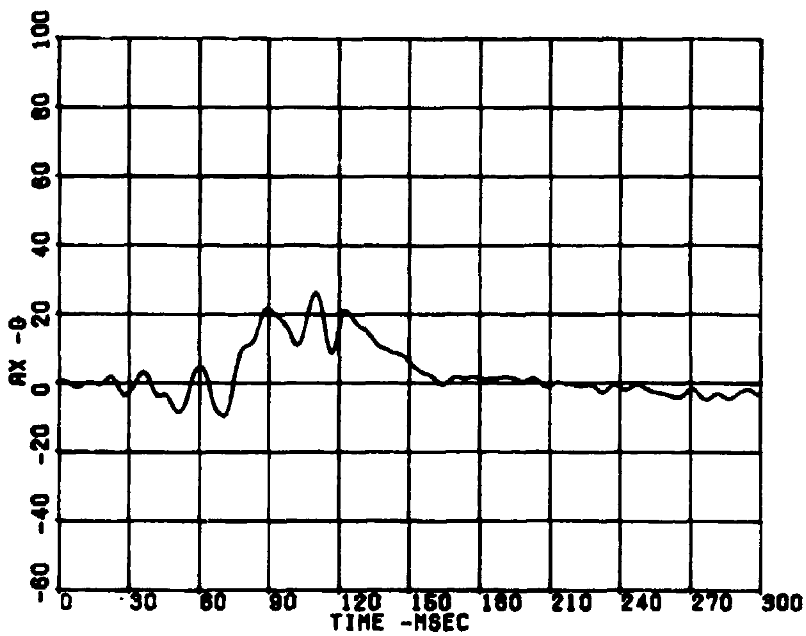


Figure D-2. Drop Test: Head Acceleration - Longitudinal.

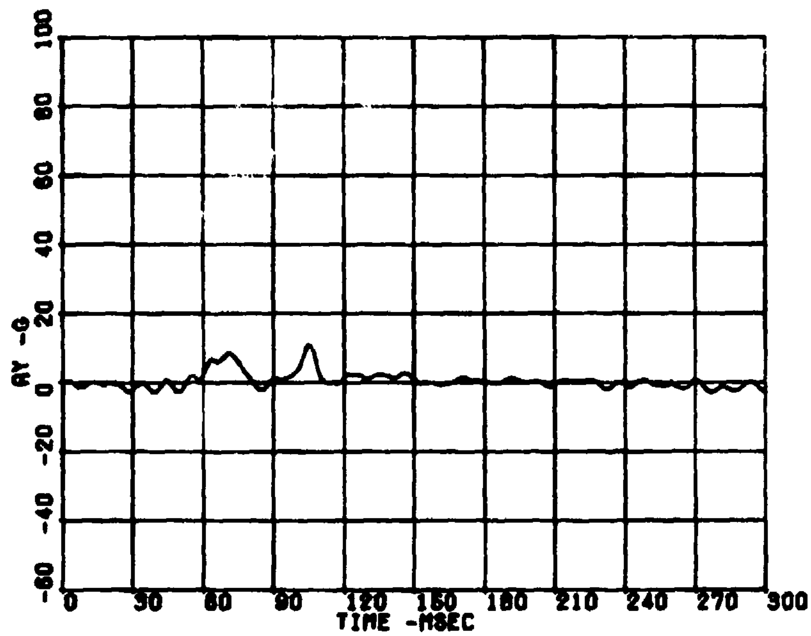


Figure D-3. Drop Test: Head Acceleration - Lateral.

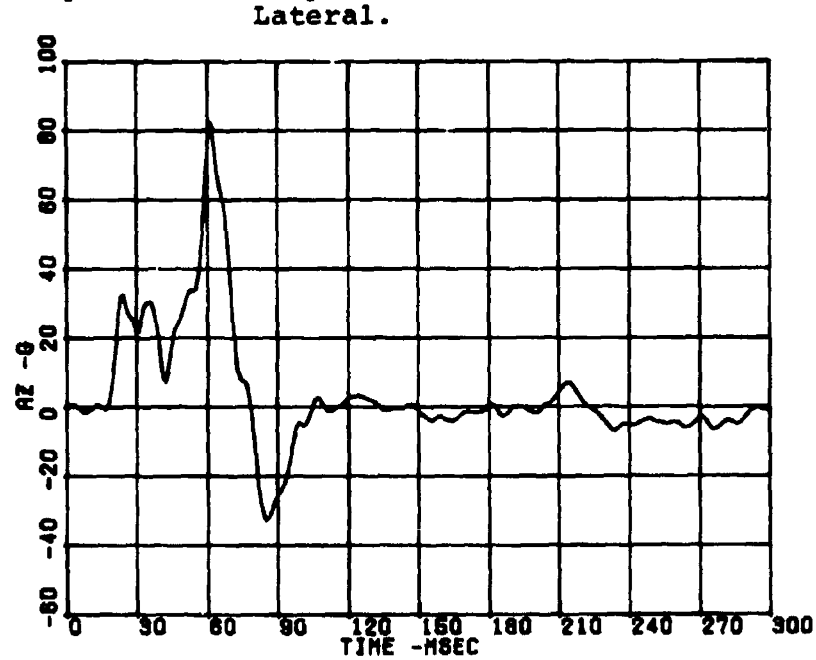


Figure D-4. Drop Test: Head Acceleration - Vertical.

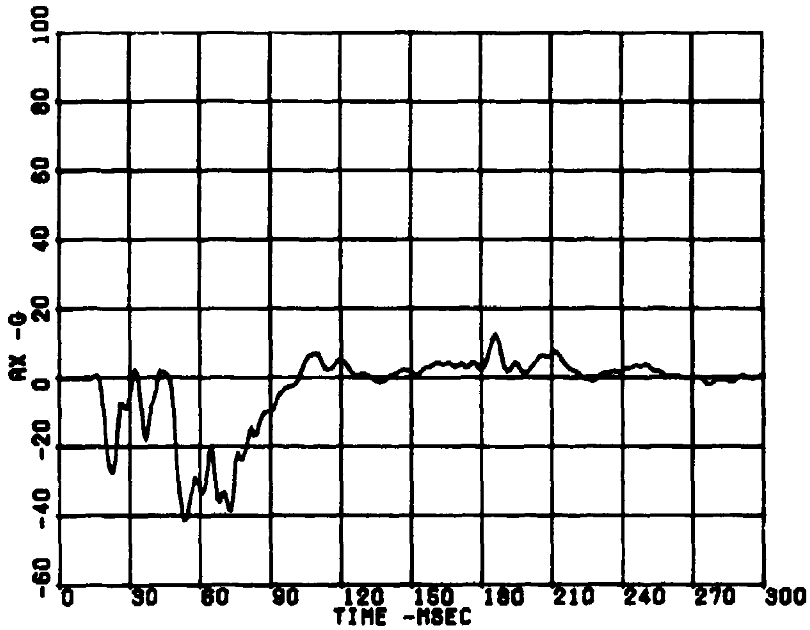


Figure D-5. Drop Test: Chest Acceleration - Longitudinal.

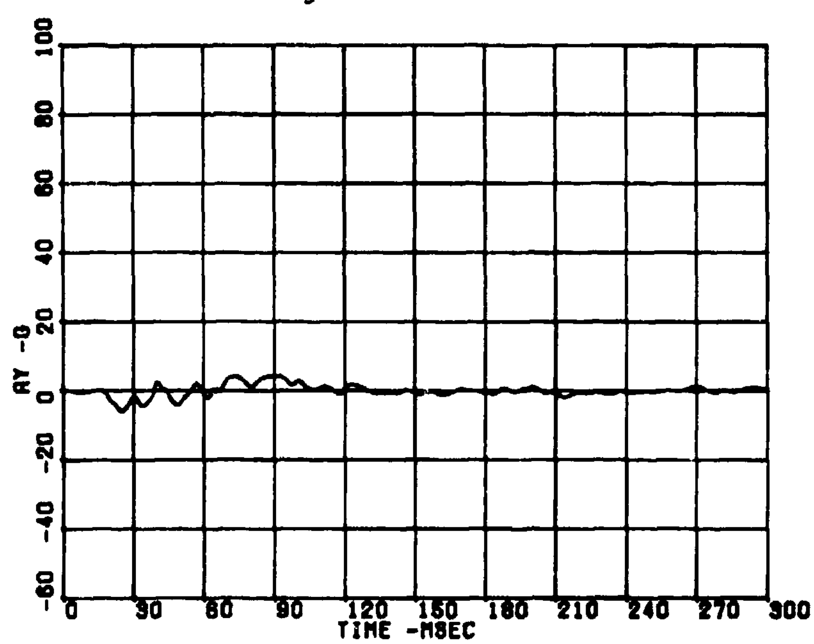


Figure D-6. Drop Test: Chest Acceleration - Lateral.

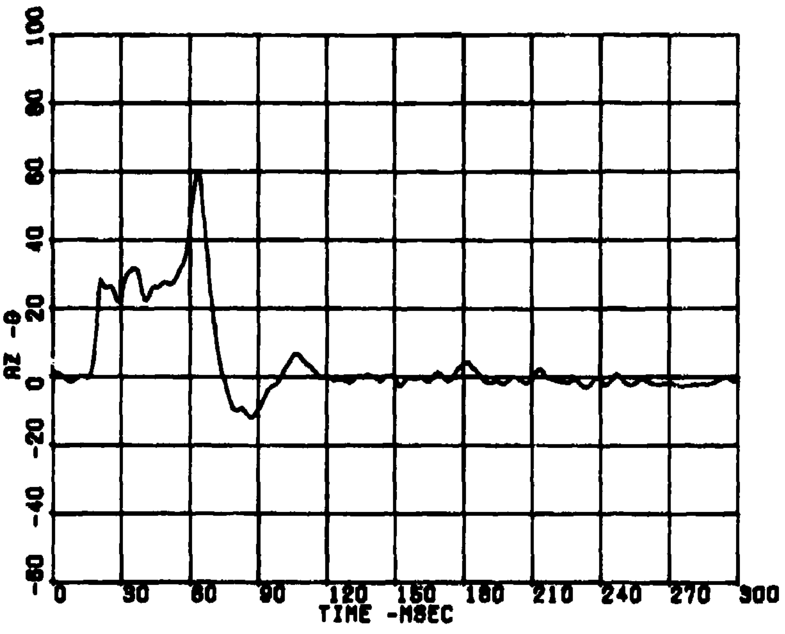


Figure D-7. Drop Test: Chest Acceleration - Vertical.

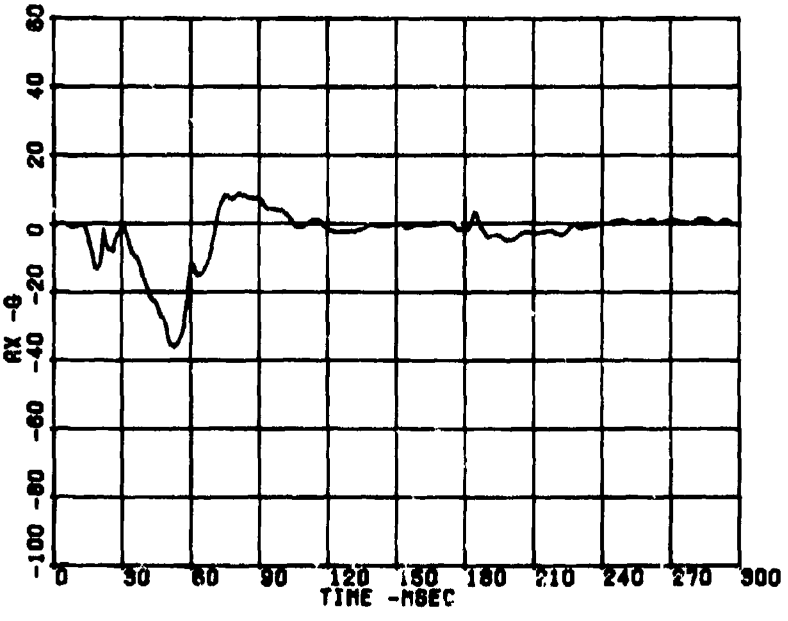


Figure D-8. Drop Test: Pelvis Acceleration - Longitudinal.

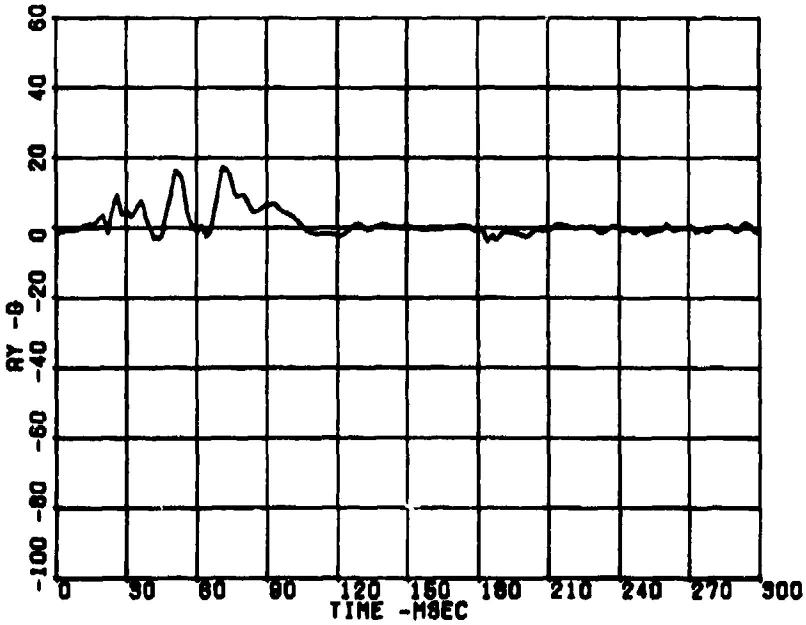


Figure D-9. Drop Test: Pelvis Acceleration - Lateral.

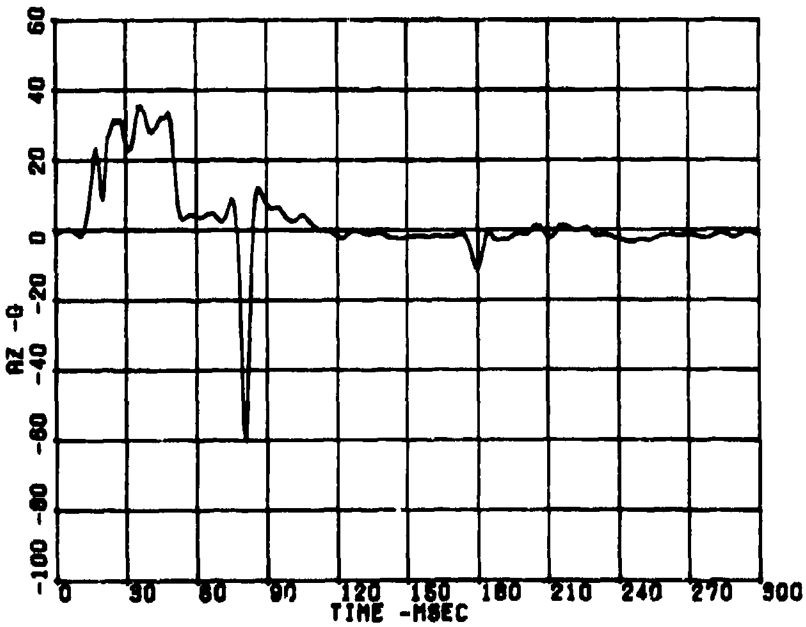


Figure D-10. Drop Test: Pelvis Acceleration - Vertical.

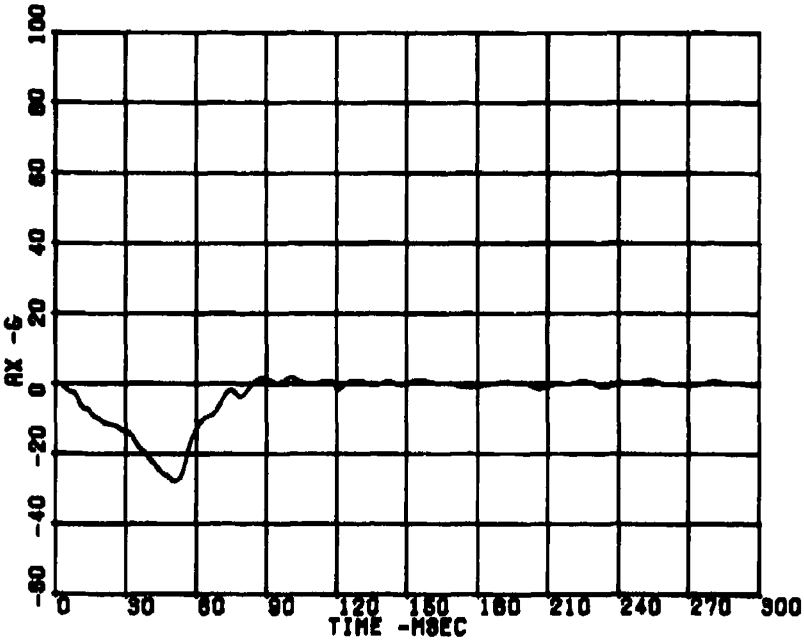


Figure D-11. Drop Test: Seat Pan Acceleration - Longitudinal.

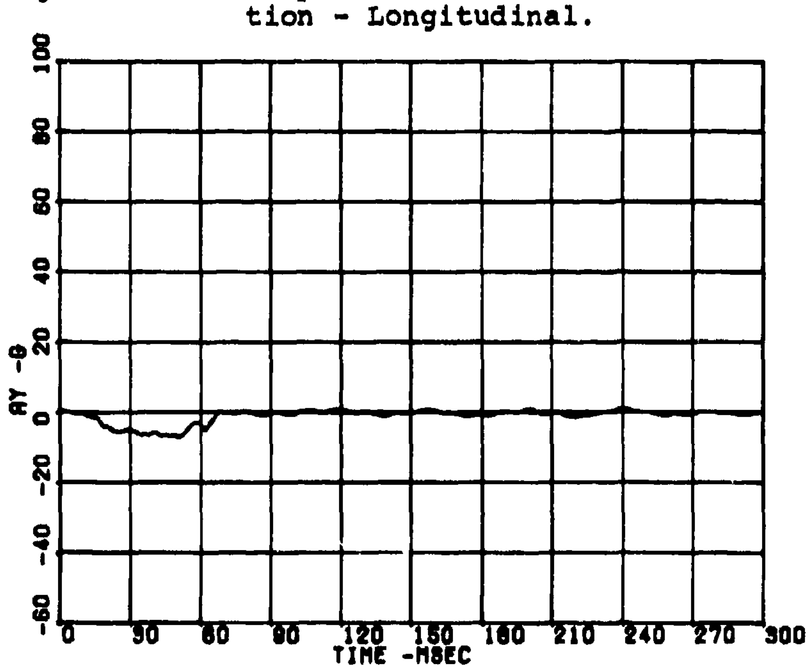


Figure D-12. Drop Test: Seat Pan Acceleration - Lateral.

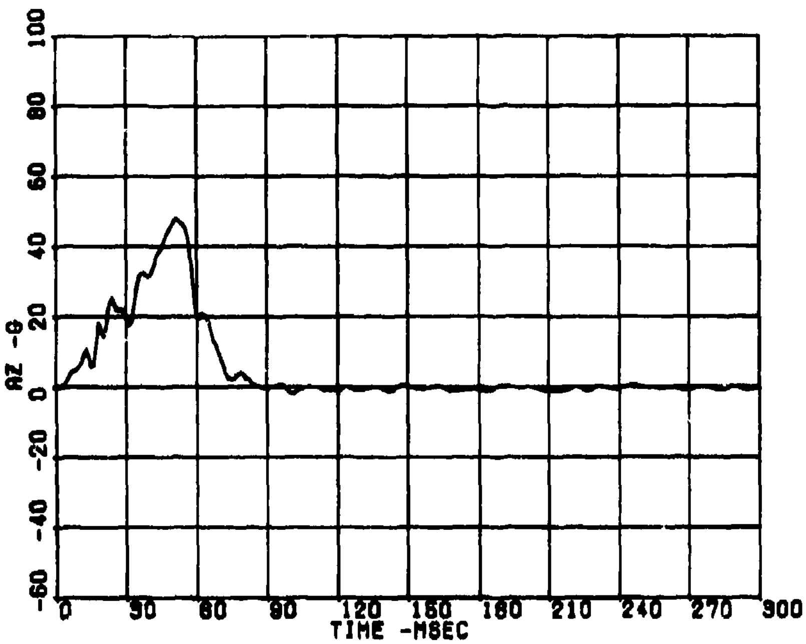


Figure D-13. Drop Test: Seat Pan Acceleration - Vertical.

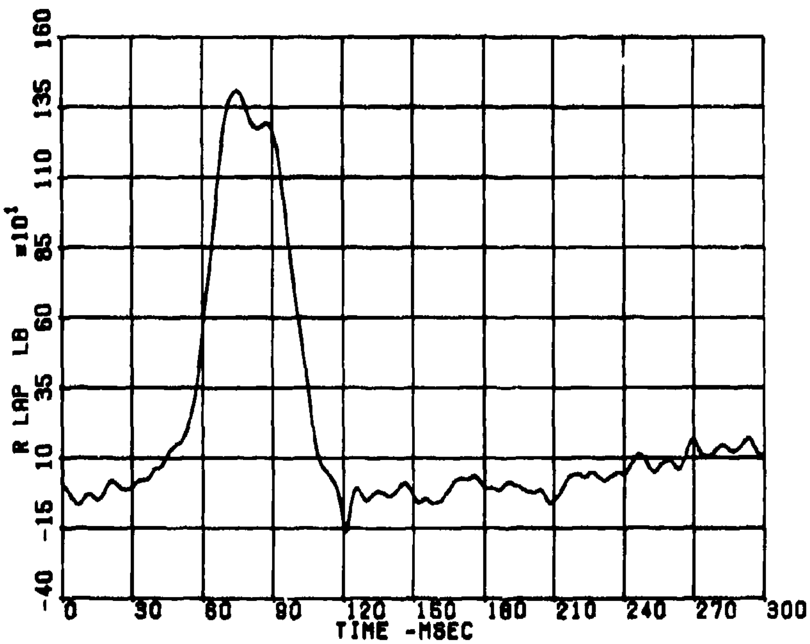


Figure D-14. Drop Test: Right Lap Belt Load.

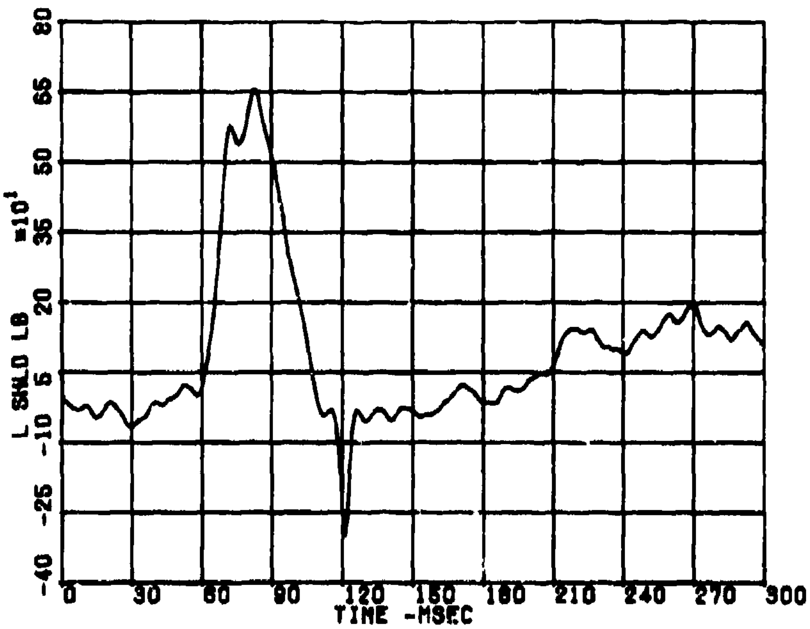


Figure D-15. Drop Test: Left Shoulder Strap Load.

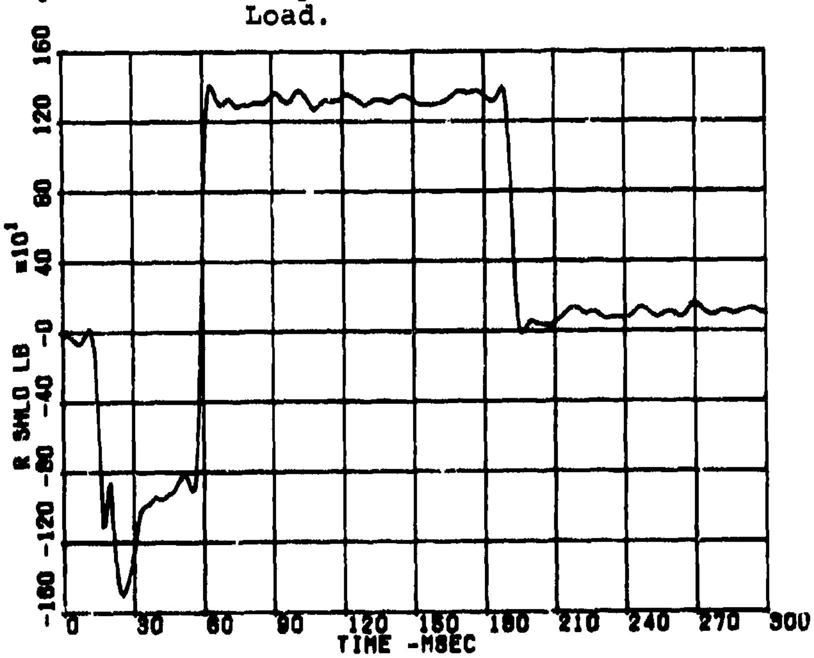


Figure D-16. Drop Test: Right Shoulder Strap Load.

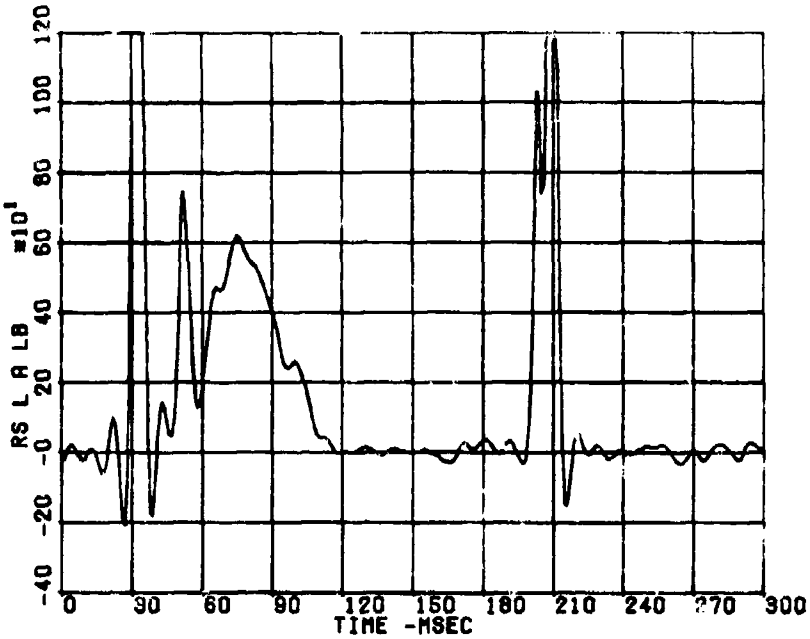


Figure D-17. Drop Test: Reflected Strap Load - Left Anchor.

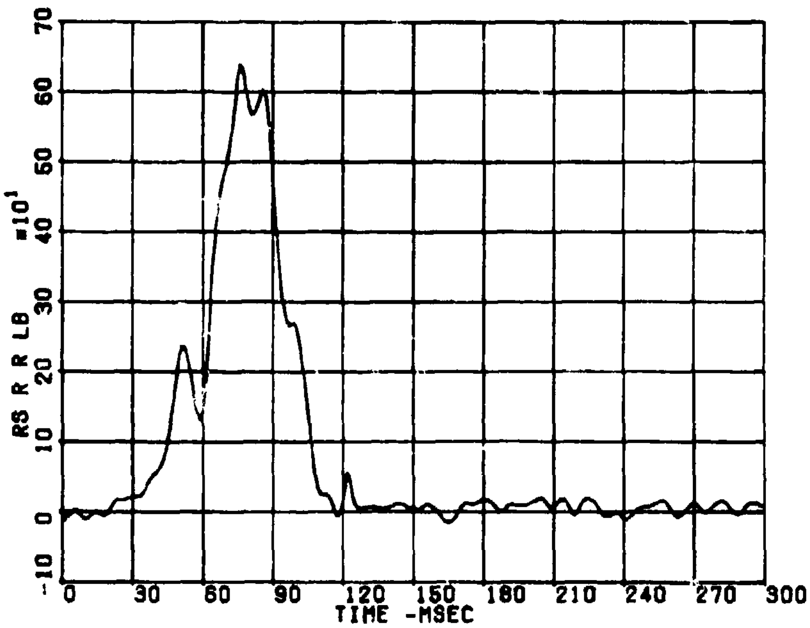


Figure D-18. Drop Test: Reflected Strap Load - Right Reel.

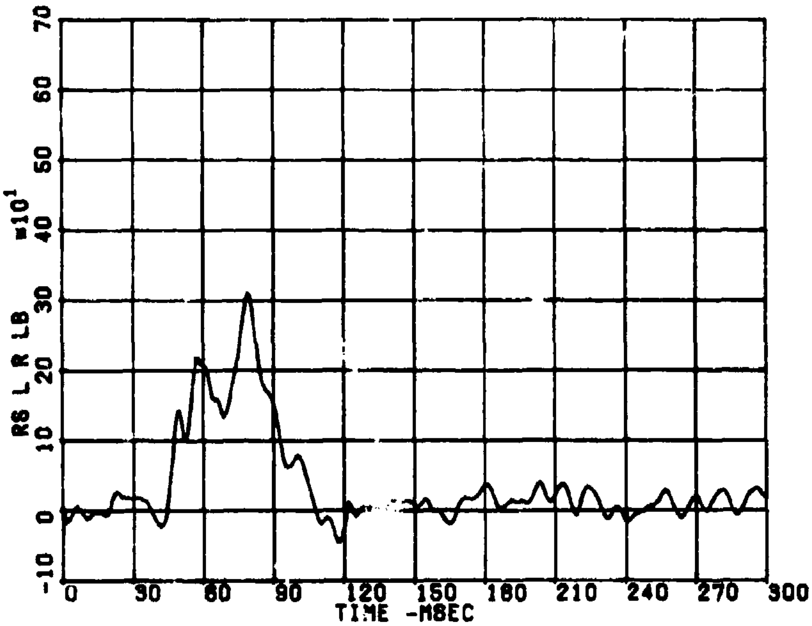


Figure D-19. Drop Test: Reflected Strap Load - Left Reel.

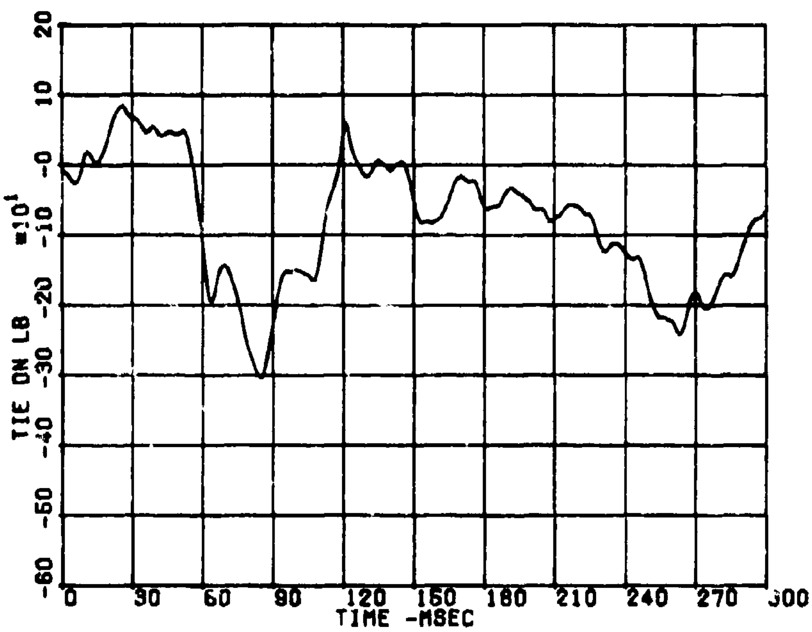


Figure D-20. Drop Test: Tie-Down Strap Load.

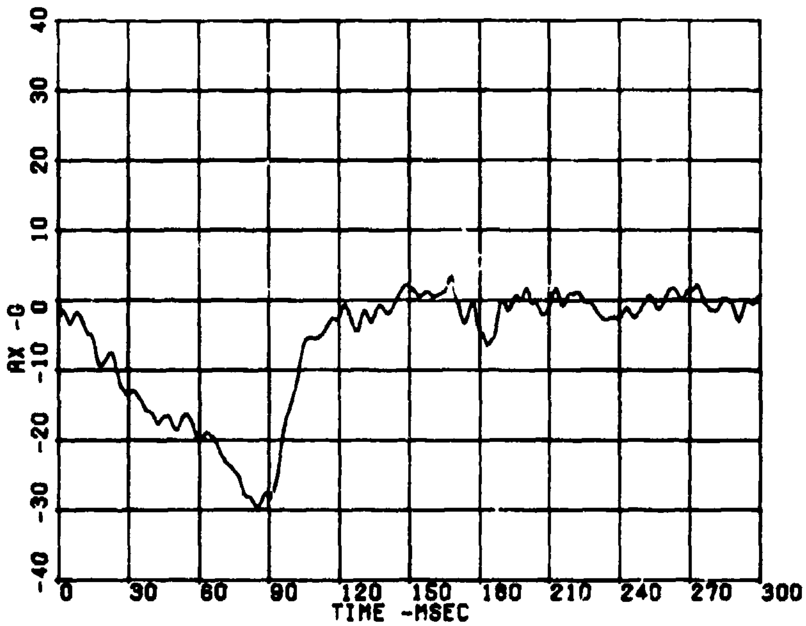


Figure D-21. Sled Test: Input Acceleration.

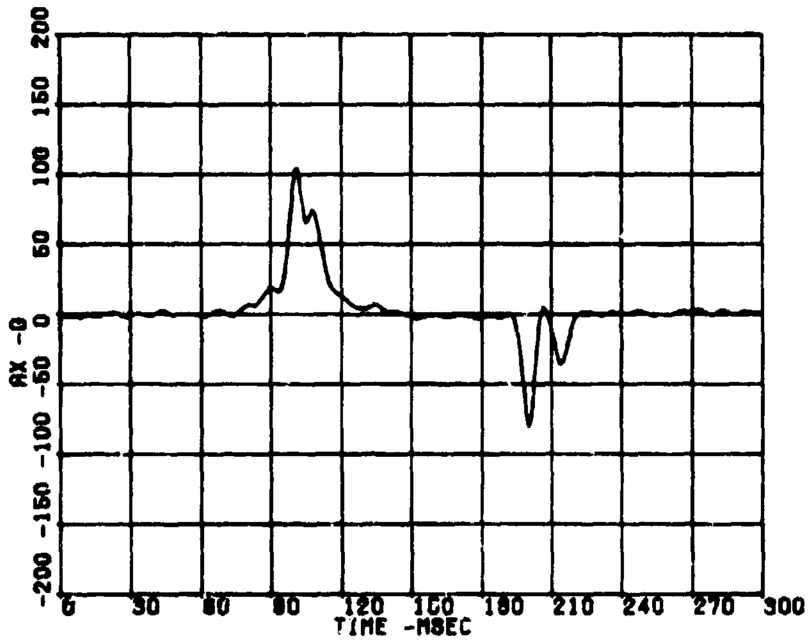


Figure D-22. Sled Test: Head Acceleration - Longitudinal.

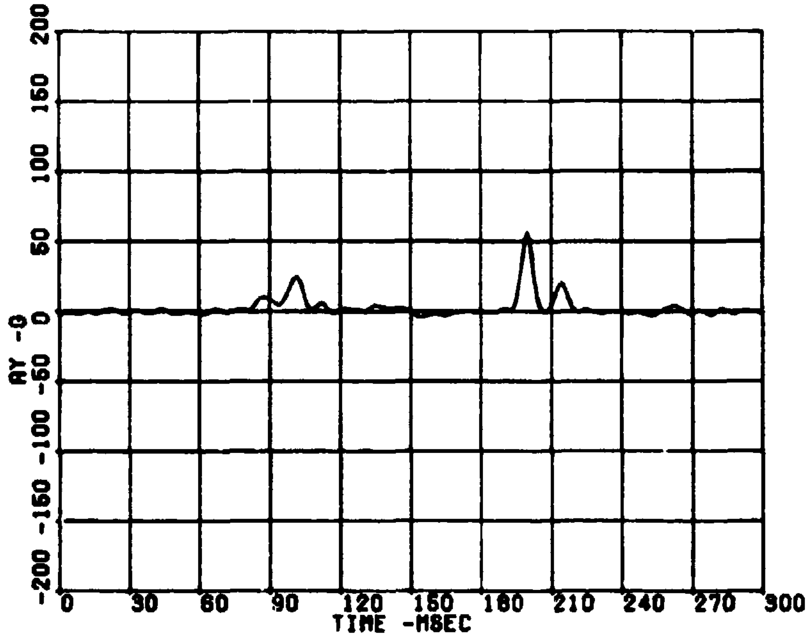


Figure D-23. Sled Test: Head Acceleration - Lateral.

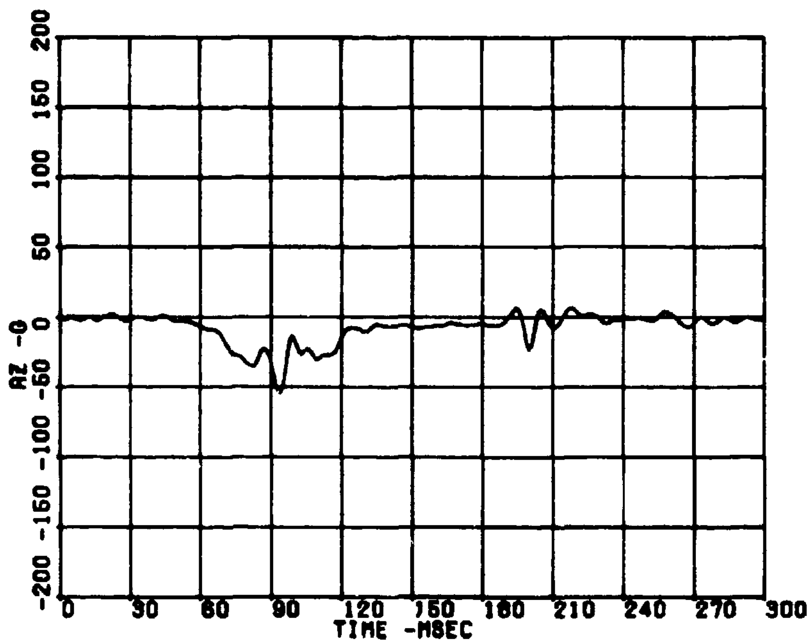


Figure D-24. Sled Test: Head Acceleration - Vertical.

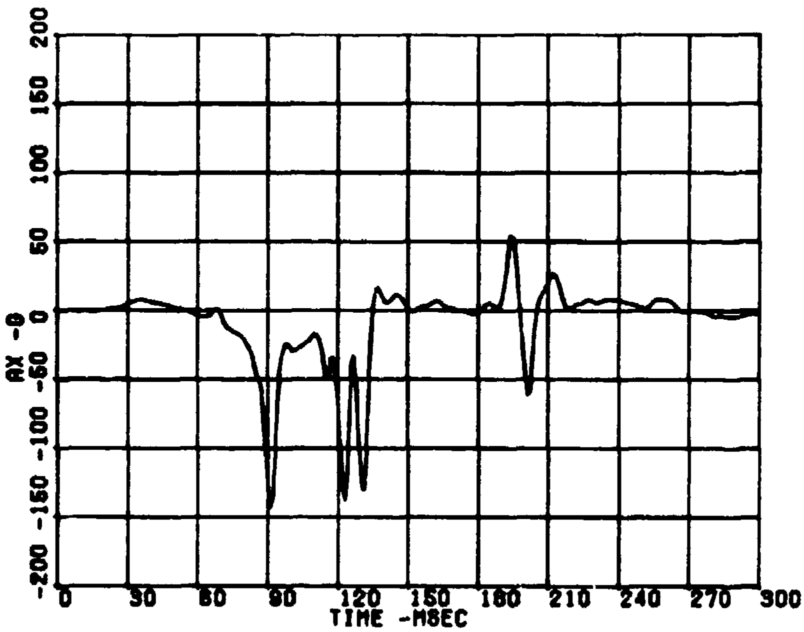


Figure D-25. Sled Test: Chest Acceleration - Longitudinal.

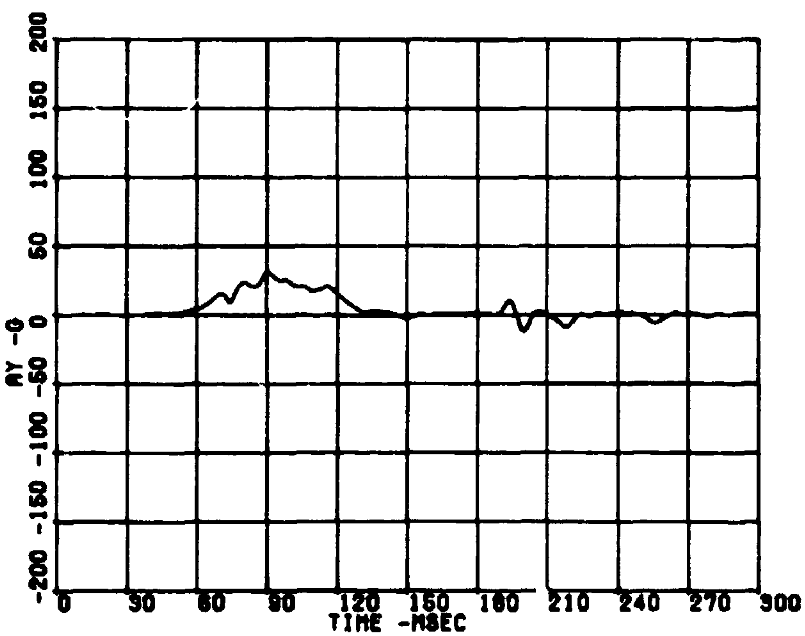


Figure D-26. Sled Test: Chest Acceleration - Lateral.

Figure D-27. Sled Test: Chest Acceleration - Vertical.

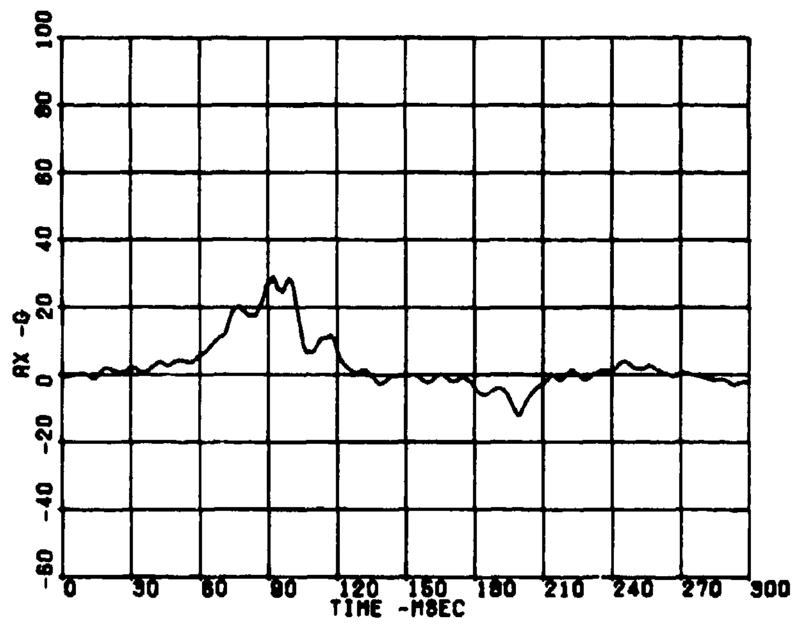


Figure D-28. Sled Test: Pelvis Acceleration - Longitudinal.

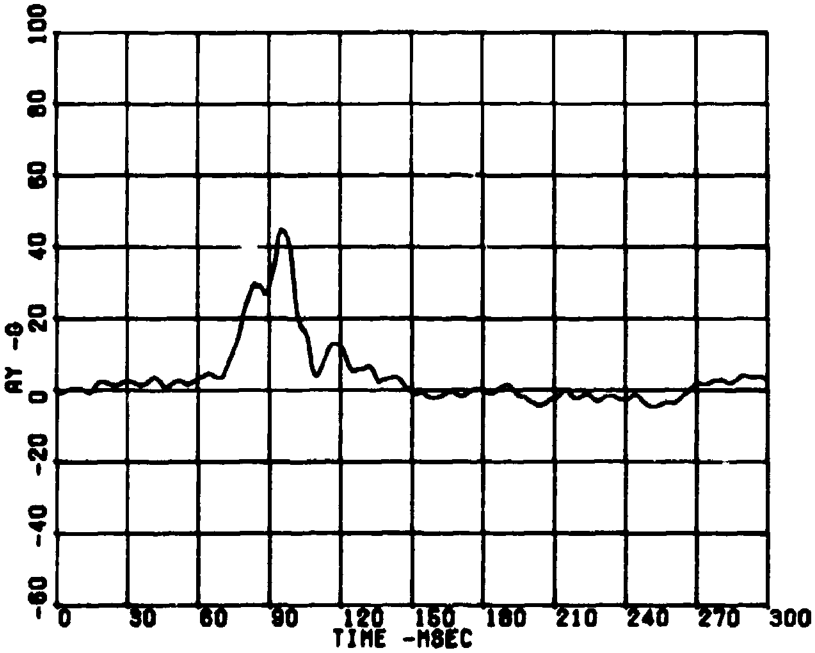


Figure D-29. Sled Test: Pelvis Acceleration - Lateral.

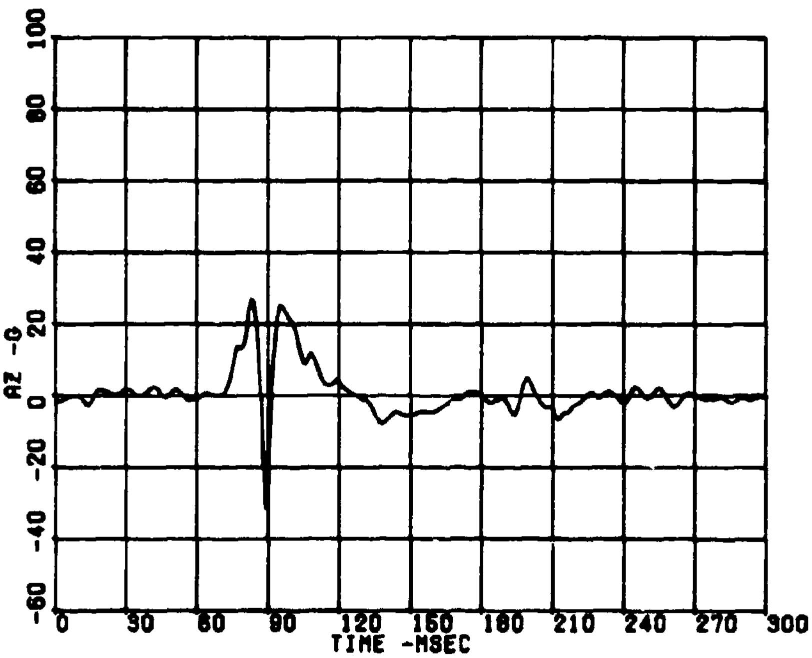


Figure D-30. Sled Test: Pelvis Acceleration - Vertical.

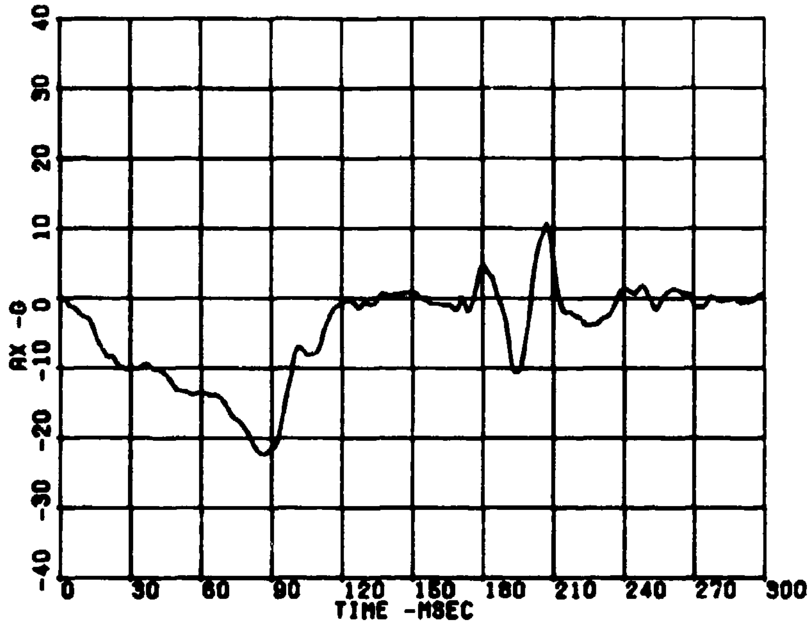


Figure D-31. Sled Test: Seat Pan Acceleration - Longitudinal.

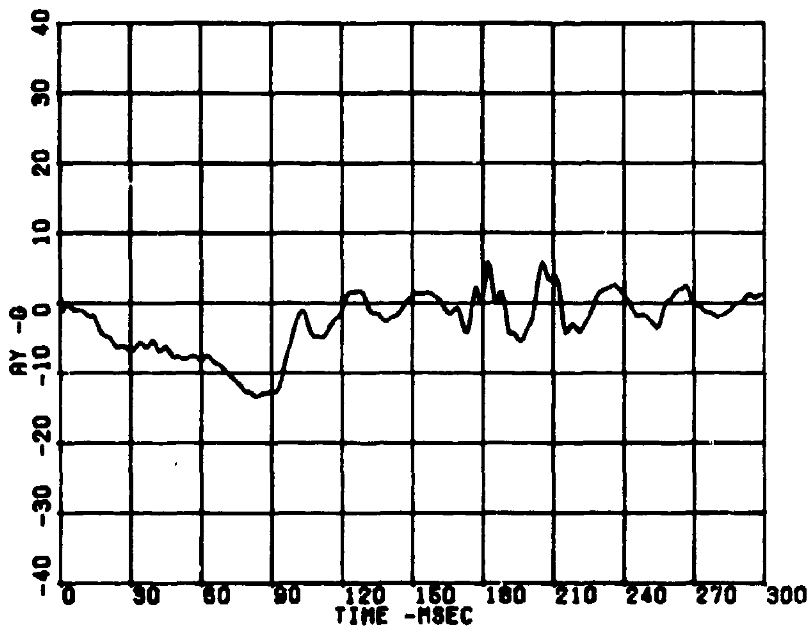


Figure D-32. Sled Test: Seat Pan Acceleration - Lateral.

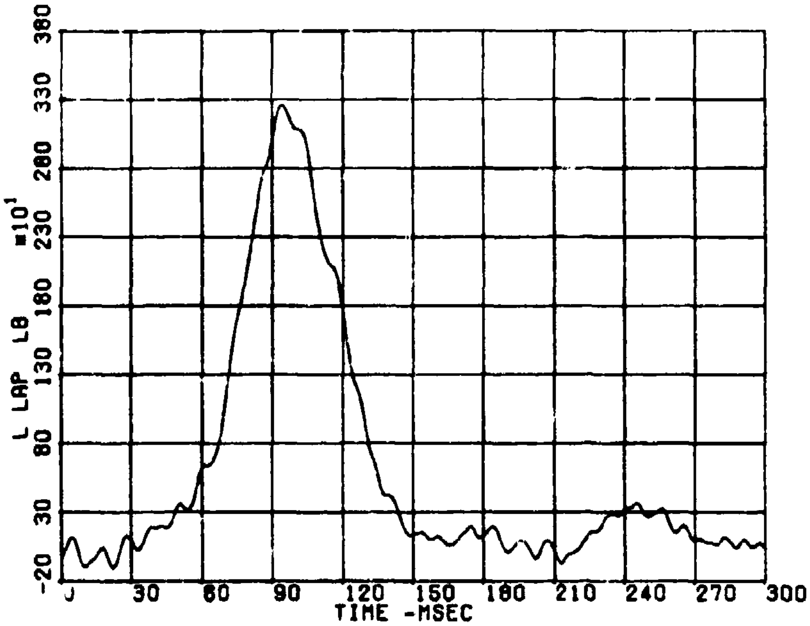


Figure D-33. Sled Test: Left Lap Belt Load.

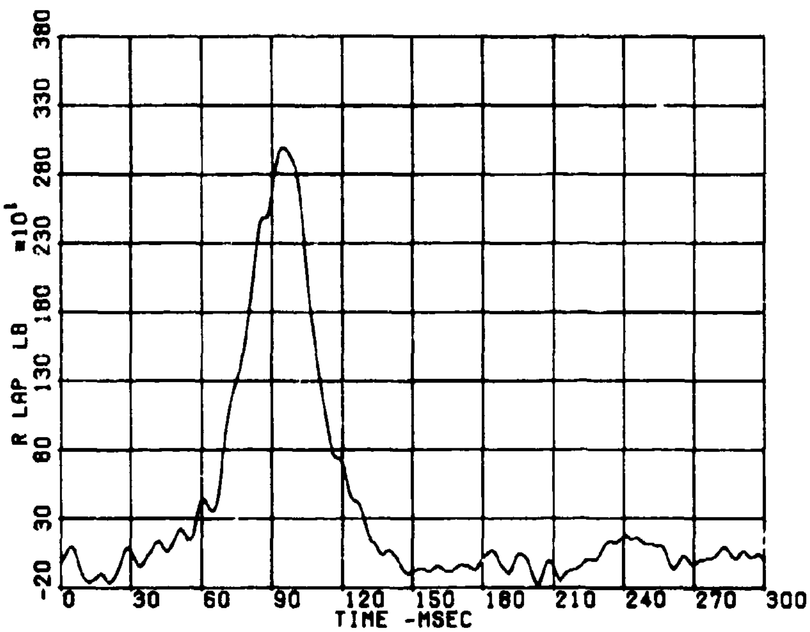


Figure D-34. Sled Test: Right Lap Belt Load.

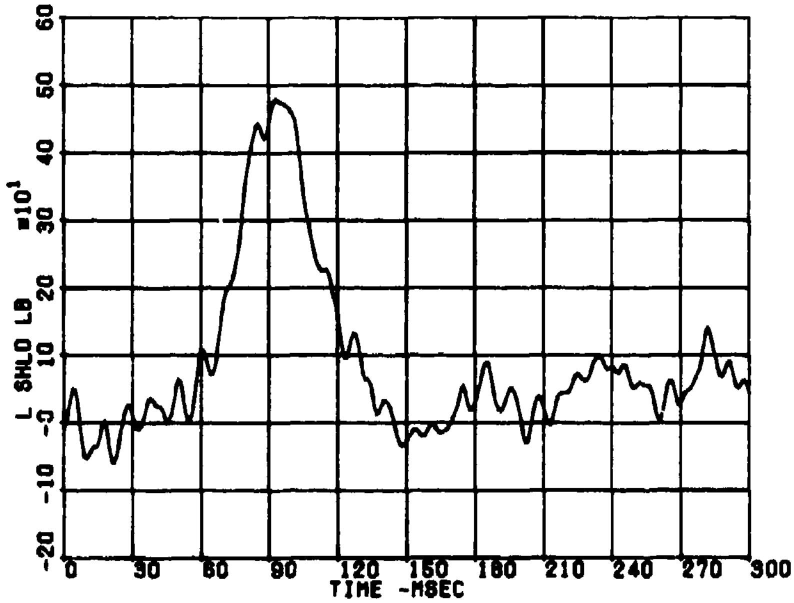


Figure D-35. Sled Test: Left Shoulder Strap Load.

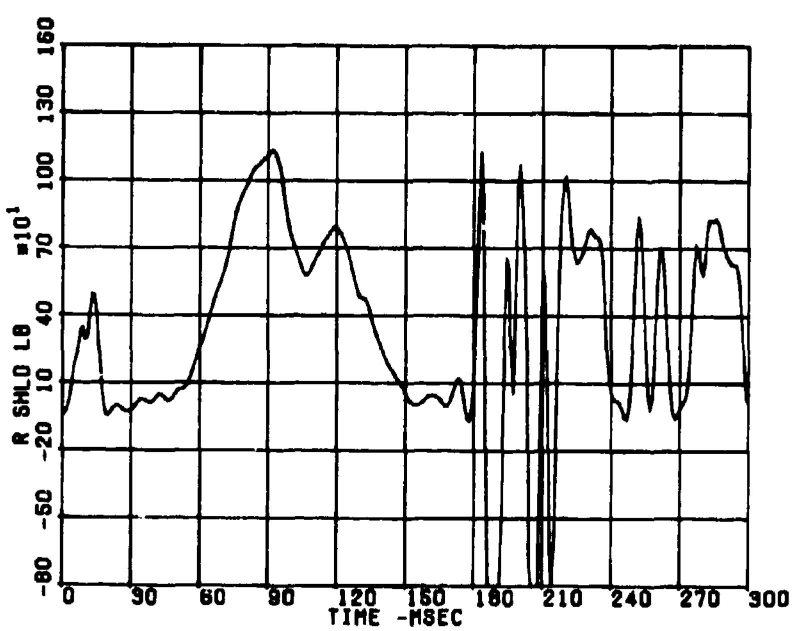


Figure D-36. Sled Test: Right Shoulder Strap Load.

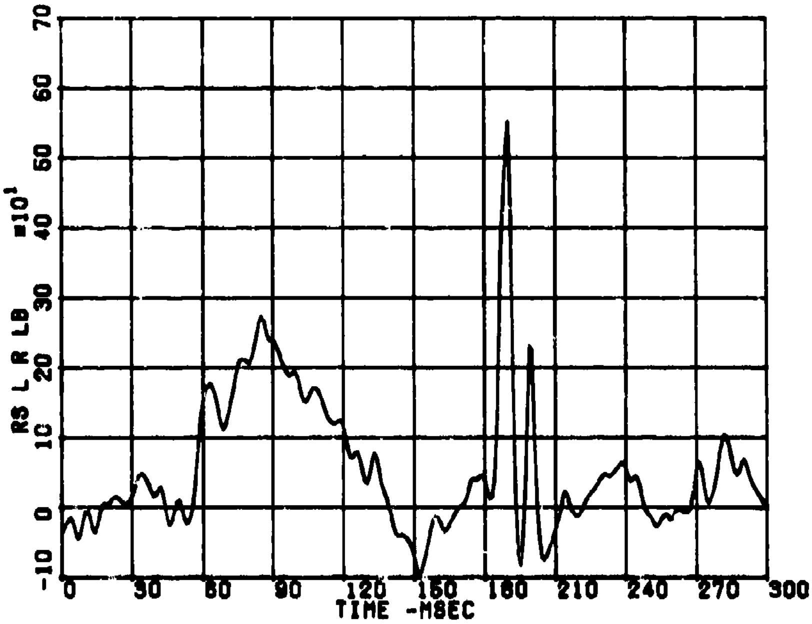


Figure D-37. Sled Test: Reflected Strap Load - Left Reel.

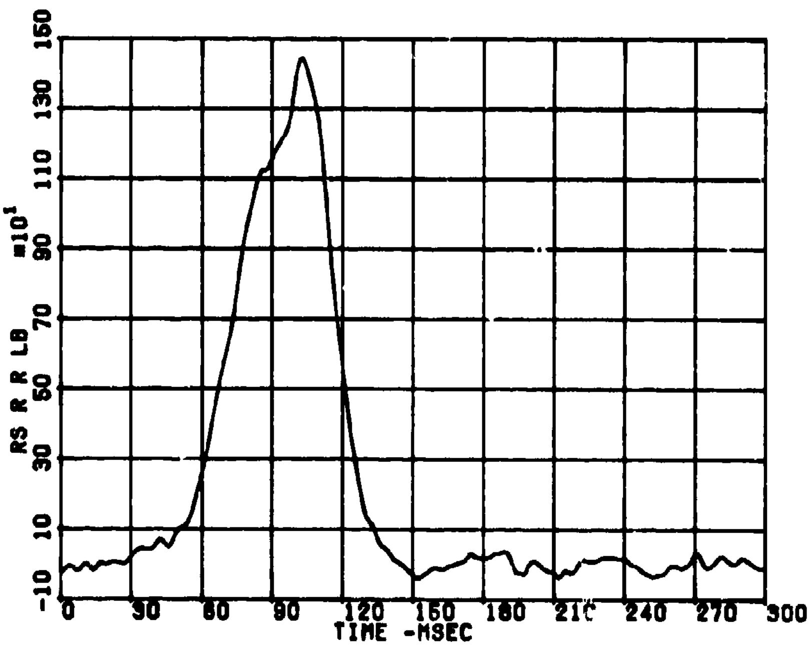


Figure D-38. Sled Test: Reflected Strap Load - Right Reel.

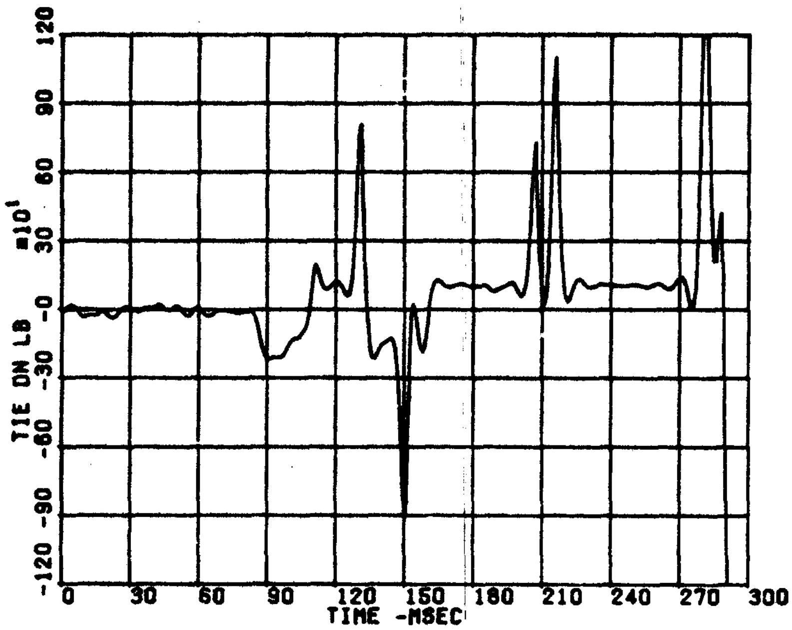


Figure D-39. Sled Test: Tie-Down Strap Load.

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